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# PROCEEDINGS OF THE EXPERT CONSULTATION TO EXAMINE CHANGES IN ABUNDANCE AND SPECIES COMPOSITION OF NERITIC FISH RESOURCES

San José, Costa Rica, 18-29 April 1983

# ACTAS DE LA CONSULTA DE EXPERTOS PARA EXAMINAR LOS CAMBIOS EN LA ABUNDANCIA Y COMPOSICION POR ESPECIES DE RECURSOS DE PECES NERITICOS

San José, Costa Rica, 18-29 de abril de 1983

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SAN JOSE, COSTA RICA
18-29 ABRIL 1983

Edited by
Editadas por

G.D. Sharp and/y J. Csirke
Fisheries Department/Departamento de Pesca

**A preparatory meeting for the FAO World Conference on Fisheries Management and Development**

**Una reunión preparatoria para la Conferencia Mundial de la FAO sobre Ordenación y Desarrollo Pesqueros**

Food and Agriculture Organization of the United Nations
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## PREPARATION OF THIS DOCUMENT

These proceedings consist of the papers that were presented and discussed during the Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources held in San José, Costa Rica, 18-29 April 1983. The Reports of the Expert Consultation are published in Volume 1 and the Proceedings in Volumes 2 and 3 of this FAO Fisheries Report No. 291.

This volume contains a brief introduction and summary of the Expert Consultation, followed by Part 1 of the Proceedings, with the regional reviews describing environmental and resources changes and related fishery responses. Papers dealing with localized and comparative studies, impacts of environmental and resources variability on human communities, and application of methods and theory are published in Volume 3. All papers are published in the original language in which they were presented to the consultation, either in English or Spanish, with a summary in the other language.

This document was reviewed and edited by Drs. J. Csirke and G.D. Sharp, Technical Secretaries of the Expert Consultation. Mrs. Yvette Corsetti and Miss Graciela Segura were responsible for the bulk of the typing and preparation of this volume, aided at different times by Doris Dearing, Sally Den Hertog-Riccardi, Jacqueline Ellis, Suzanne Tyrrell-Donati, Jean Valletta, Janet Webb-Savini. Ms. Kathleen T. Dorsey assisted with the proof-reading and Drs. S. Garcia and S. Chikuni helped with the review of some of the papers.

This Expert Consultation was one of the preparatory metings for the FAO World Conference on Fisheries Management and Development. The consultation was organized by FAO with the support of IOC, CPPS, DANIDA, ICLARM, ICSEAF, IDB, SELA and WMO.

## PREPARACION DE ESTE DOCUMENTO

Estas actas contienen las contribuciones que fueron presentadas y discutidas durante la Consulta de Expertos para Examinar los Cambios en la Abundancia y Composición por Especies de Recursos de Peces Nerlticos que se realizó en San José, Costa Rica, del 18 al 29 de Abril de 1983. Los Informes de la Consulta de Expertos están publicados en el Volumen 1 y las actas en los Volúmenes 2 y 3 de este FAO, Informes de Pesca No. 291.

Este volumen contiene una breve introducción y resumen de la Consulta de Expertos, seguida de la Parte 1 de las actas, con las contribuciones donde se hacen análisis regionales de los cambios en el medio ambiente y en los recursos y de las correspondientes reacciones en el campo de la pesca. En el Volumen 3 se publican las contribuciones sobre estudios localizados y comparativos, sobre las repercusiones de la variabilidad del ambiente y de los recursos en las comunidades humanas, y sobre la aplicación de métodos y teorla. Todas las contribuciones se han publicado en el idioma original en que fueron presentadas a la Consulta de Expertos, ya sea español o inglés, con un resumen en el otro idioma.

Este documento ha sido revisado y editado por los Drs. J. Csirke y G.D. Sharp, los dos Secretarios Técnicos de la Consulta de Expertos. La Sra. Yvette Corsetti y la Srta. Graciela Segura fueron responsables de la mayor parte del trabajo de mecanografiado y preparación de este volumen, con la asistencia temporal de Doris Dearing, Sally Den Hertog-Riccardi, Jacqueline Ellis, Suzanne Tyrrell-Donati, Jean Valletta, Janet Webb-Savini. La Sra. Kathleen T. Dorsey asistió en la corrección de las pruebas y los Drs. S. Garcia y S. Chikuni asistieron con la revisión de algunos de los documentos.

Esta Consulta de Expertos fue una de las reuniones preparatorias para la Conferencia Mundial de la FAO sobre Ordenación y Desarrollo Pesqueros. La consulta fue organizada por la FAO con el apoyo de la COI, BID, CIPASO, CPPS, DANIDA, ICLARM, OMM y SELA.

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## PREFACE

While reviewing and editing these proceedings for publication we realized that we should include a brief statement of the present position of the investigations in fisheries and fisheries related science. This, we agreed, was necessary because of the distinctive and numerous specialized subjects that are dealt with in the papers included in these proceedings. We thought that any reader might benefit from a comparison of the past and present situation, and perhaps therefore obtain a better perspective on where or in which directions fishery research should be going.

Several names of well known fishery scientists come to mind who might provide the critical, yet positive messages about what had or had not been done in the past, what needed attention now and perhaps directions to take in the future.

To our surprise and satisfaction we found these kinds of messages clearly stated in an existing text. The following excerpts were even already available under a chapter headed, "Review of the Present Position of Investigations":

"The study of methodically collected material, embracing a period of many years, has demonstrated the existence of an intimate relation between the fluctuations in the numerical value of the stock of fish and the yield of the great fisheries...

The opinion generally prevalent hitherto [is] that the renewal of the stock of fish [takes] place, as in the case of the increase of any human population, by means of a more or less constant annual increment in the form of new individuals; the results arrived at, however, indicate that this renewal, in the case of the species invetigated, is of a highly irregular nature...

These results naturally lead us to inquire into the causes, or better, the natural phenomena which occasion these peculiar fluctuations in the renewal of the stock; the hydrographical or biological conditions which give rise to the occurrence of rich or poor year classes of fish. The problem is one of unquestionable difficulty, embracing as it does all the conditions which in any way affect the fish from the egg stage to the time when they are caught. It will therefore appear most probable that the renewal of the fish stock, as in the case of any stock on land, is dependent upon many factors, all necessary, and all more or less variable. Thus in each individual instance, the missing factor will appear to be that which determines the ultimate result. Only experience extending over a long period of time can enable us to ascertain with certainty the variation of the different determining factors, and to discover how far one and the same factor is in all cases of decisive importance, or whether, in the course of the development of the fish, there may be several, each varying so greatly as to possibly determine the character of the year's production. It is evident from this, that a closer study of the laws which govern the renewal of the stock will naturally necessitate extended observation of the natural conditions which prevail in the sea, and even of conditions which at first sight have little or no connection with fishery questions...

The numerical value of a year class is apparently determined at a very early stage, and continues in approximately the same relation to that of other year classes throughout the life of the individuals...

The first question which then arises is whether the numerical value of the year classes is dependent upon the extent of the spawning, i.e., the number of eggs produced...

Little can therefore be stated as yet beyond the results indicated by the comparison between the quantity of roe observed during the fishery, and the number of fish in subsequent years. It will be remembered, that this comparison showed the very years in which the quantity of roe at [...] was least to be those which produced the richest year classes. This being so, it is difficult to avoid the conclusion that the actual quantity of eggs spawned is not a factor in itself sufficient to determine the numerical value of a year class. A rich spawning may produce a year class poor in numbers, while a large year class may have its origin in a year when the spawning was at its lowest...

We must therefore look to the later stages of the eggs to find the conditions which determine the numbers of individuals in any year class. This again leads us to the question, at which stage of development the most critical period is to be sought. Nothing is known with certainty as to this; such data as are available, however, appear to indicate the very earliest larval and young fry stages as most important...

A study of the conditions which determine the numerical value of the year classes can only attain its object when based upon a very extensive plan. As a matter of fact, the object can never be fully attained; new questions will constantly arise, as the knowledge obtained creates the demand for new, and it will always be possible to increase and intensify our comprehension of the vital conditions affecting the organisms in question. A study of the fluctuations in the population of the sea, both fish and smaller organisms, and thus of the whole organic life existent in the ocean, is therefore the soundest possible basis for marine research, whether with theoretical or practical ends in view. There is moreover, scarcely any other question which is so well calculated to focus the attention of men engaged upon different branches of science, as this must necessarily be the case where several investigators are at work on board the same vessel...

The constantly increasing knowledge of the hydrographical and biological conditions upon which the numbers of the organisms, and especially of the fish, so greatly depend, will naturally be of the greatest importance. Perusal of the mass of fantastic guesses, assertions and suggestions which have been published in various works or in the press, with the object of combating these fluctuations, will suffice to show that only to have led the general trend of ideas into a right or reasonable direction would in itself be an achievement worth all the amount of work involved...

In the interest of biological research, also, it must be of the greatest importance to ascertain the nature of the laws which govern the renewal of the animal population, especially when taking into consideration all that has been written from time to time about overpopulation and the struggle for existence in the animal world, all from the point of view of human conditions...

The knowledge obtained will also be of great practical value in considering the question of possible decrease in the stock due to overfishing, and will at least serve to show that the statement of the fishery statistics can only be safely employed for the elucidation of these problems, when the fluctuations due to natural causes are known...

The principal and most directly practical object in connection with these investigations is that of furnishing the fishermen and others immediately interested with reliable information as to the present condition of the stock and probable alterations in the same, in other words, of obtaining material on which to base predictions as to the expected course of fluctuations in the stock...

I am perfectly aware of the impossibility of making definite statements as to the value of results not yet attained; the facts as at present known should, however, suffice to indicate the improbability of obtaining any adequate basis for such predictions from investigations as to the causes of the fluctuations. Even if it were possible, for instance, to assert, with scientific accuracy, that the nourishment of the youngest larvae, or the passive movement of the young fry, should be regarded as the determining factor for subsequent wealth or poverty of a year class, it is hardly likely that such knowledge would suffice for annual predictions as to the future size of the stock. It would in any case then be necessary to know far more of various other conditions than is at present the case...

These are just a few of the many statements made by Johan Hjort in 1914 (the excerpts are from Rapp.P.-V.Réun.CIEM, 20:205-10) regarding the past, and present, position of investigations in fisheries and fisheries-related sciences. Probably the style and wording will be different, but we should not be surprised to find the same kind of statements in many of the modern fishery science works.

We hope that repeating a four-generation-old challenge disturbs, and therefore might stimulate, those readers who may have the means and opportunities needed to face these issues. The increase in knowledge and archived facts since Hjort's efforts has been immense; not all his queries have been answered, and, as he predicted, new knowledge brought new questions to the forefront. Advances have been made, particularly in the realization of the roles of physics, meteorology, and solar energy fluctuations on the variations in the oceans and general biosphere. There are energetic groups of scientists from many specialities who are making efforts toward a multi-disciplinary fishery science. Many good examples of these kinds of efforts are evident among the contributions and contributors to this Expert Consultation.

If Man is to ever approach harmony with nature, particularly with the oceans and the living resources in them, then more attention needs to be given to the resolution of these basic problems, so eloquently stated by Johan Hjort seventy years ago.

The Editors

# PREFACIO

Al revisar y editar las actas para su publicación, nos dimos cuenta que debíamos incluir una breve exposición sobre la situación actual de las investigaciones en el campo de la ciencia pesquera y otras ciencias relacionadas. Esto se hacía necesario debido a la variedad y características particulares de los numerosos temas que se tratan en las contribuciones incluidas en estas actas, lo que justificaba una breve introducción donde se hiciera una comparación entre la situación de las investigaciones en el pasado y en el presente, y diera al lector una perspectiva clara de la marcha y la orientación que deberían tener las investigaciones pesqueras en el futuro.

Por nuestra mente pasaron los nombres de varios científicos de renombrado prestigio que habrían podido hacer una revisión crítica, y al mismo tiempo positiva, de lo que se había hecho y lo que se había dejado de hacer en el pasado y de lo que necesitaba ser considerado en el presente y, posiblemente, dar además algunas sugerencias para el futuro.

Para nuestra sorpresa y satisfacción encontramos que precisamente el tipo de mensaje que estabamos buscando estaba a disposición de un texto ya publicado. Inclusive estos conceptos estaban enunciados en un capítulo bajo el título en inglés: "Review of the Present Position of Investigations" (Revisión de la Situación Actual de las Investigaciones).

En el prefacio en inglés nos hemos tomado la libertad de citar textualmente algunas frases y párrafos que hemos creído son las más pertinentes dado el contenido de estas actas. Aunque creemos que el lector apreciará mucho más la lectura de la versión completa del capítulo al que hacemos referencia en su forma original.

El capítulo que citamos trata entre otras cosas el tema de la estrecha relación entre las fluctuaciones de las poblaciones de peces y el rendimiento de la pesca; el rol que juega el reclutamiento en la renovación de las poblaciones de peces y la naturaleza altamente irregular de este proceso en muchos de los casos investigados.

Al ocuparse de la necesidad de investigar las causas o fenómenos naturales que ocasionan estas fluctuaciones se mencionan las condiciones hidrográficas o biológicas que dan lugar a la ocurrencia de clases anuales pobres o abundantes. Se menciona que la renovación de las poblaciones de peces depende de muchos factores, todos necesarios y todos más o menos variables, y que en cada caso individual el factor faltante es el que parecería determinar el resultado final; para investigar las leyes que gobiernan la renovación de las poblaciones de peces, se necesita extender las observaciones de las condiciones naturales predominantes en el mar e inclusive de las condiciones que a simple vista pueden tener poca o ninguna relación con la pesca.

Esta obra resalta la escasa relación encontrada entre la población desovante o la producción de huevos y la magnitud del reclutamiento subsiguiente, sugiriendo que la mayor parte de la variabilidad del reclutamiento es determinado a nivel de las fases de huevos y larvas. Se sugiere que para investigar estas fluctuaciones se requiere de planes extensos aunque se señala también que el objetivo final de estas investigaciones nunca será alcanzado totalmente ya que continuamente surgirán nuevas preguntas y el conocimiento obtenido creará la demanda por conocer más.

En la obra que citamos se menciona que el conocimiento de las fluctuaciones debidas a causas naturales es también necesario si se quiere considerar el tema de la posible disminución de las poblaciones de peces debido a la sobrepesca. Se enfatiza también que el objetivo directo y principal, y el más práctico, de estas investigaciones es el de proporcionar a los pescadores y al sector pesquero, información confiable sobre la situación actual y sobre las posibles alteraciones que pueden ocurrir.

Estos y otros conceptos cuya vigencia difícilmente puede ser puesta en discusión fueron enunciados por Johan Hjort en 1914 (Rapp.P.-V.Réun.CIEM, 20:205-10).

Creemos que comenzar una obra como ésta, repitiendo un desafío de hace cuatro generaciones puede perturbar a algunos, pero estamos seguros que ésto será una fuente de inspiración y estímulo para muchos otros, como la ha sido durante casi setenta años, particularmente para aquellos que tienen, o han tenido los medios y las oportunidades para enfocar estos aspectos. No cabe duda que los conocimientos y adelantos logrados desde la época de Johan Hjort son inmensos, pero no todas sus preguntas e interrogantes han sido resueltas y como él mismo anunció, los nuevos conocimientos traen consigo nuevas preguntas que resolver. Se han hecho grandes avances, particularmente en cuanto a la percepción del papel que juega en las fluctuaciones de los océanos y de la biósfera, la física, la metereología y la energía solar. Hay muchos grupos de científicos de diversas especialidades que se encuentran trabajando activamente y se están esforzando para hacer que la ciencia pesquera tenga el enfoque multidisciplinario que necesita. Entre las contribuciones y participantes en esta Consulta de Expertos creemos que hay algunos buenos ejemplos de este tipo de esfuerzo.

Creemos que si algún día el hombre volverá ha estar en perfecta harmonía con la naturaleza, particularmente con los océanos y los recursos vivos que en él se encuentran, es necesario que se de más atención a la solución de algunos de los problemas básicos presentados en forma tan elocuente por Johan Hjort hace setenta años.

Los Editores

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## INTRODUCTION AND SUMMARY OF THE EXPERT CONSULTATION

Nearly one hundred years of developments in fisheries science have contributed to the present basis for the management of fisheries. However, recent events in the Atlantic and Pacific Oceans that have affected the climate and biological production over extensive areas have also had remarkable impact on the views of many fishery scientists and managers about neritic fish resources and what to expect from them. This, of course, increases the demand for new and improved methods and theory.

In some areas, such as the North Atlantic and North Pacific, complex and highly developed fisheries are measured, monitored and reviewed periodically in order to plan and implement more or less elaborated mechanisms for fisheries management. There are, however, many other areas where the information for managing fisheries are not sufficient or management based on scientific information is just not common practice.

Of course one could argue that management and the information for it will evolve where and as it is needed, but if we are to review typical management effectiveness, as applied to many fisheries, we may find that, mostly when it was needed, the results were poor or even tended to stimulate competition, over-exploitation and either resource collapse or failure of the economics of the fishery, or both. Examples are numerous, and several cases are documented in this volume.

The major failing of available fishery monitoring tools and methods is that they tend to integrate out variation and generate mean expectations which are not conservative during resource recessions, for whatever reasons, and they tend to under-estimate what is going on during growth periods. While equilibrium or steady-state processes are useful conceptual devices, they are inadequate for dealing with dynamic and highly variable resources which are themselves merely reflections of larger, dynamic ecological systems, and the related climate-ocean driven processes which are so difficult to measure or forecast on any but the shortest time-space scales. Certainly, new concepts and alternative methods are needed to properly deal with fisheries and fishery resources that are obviously affected by environmental changes that usually go unnoticed by conventional fishery monitoring systems and available measuring tools. One consequence of this is that management options end by being limited to very short-term reactions based on short time and limited space-scale forecasts, if any management reaction occurs at all.

Even the concept of short-term balancing, where some key parameters can be assumed to be constant, finds itself in contrast with recent events in some major neritic zones. For example, there have been unprecedent blooms of valuable cephalopods and their fisheries off northwest Africa; off equatorial Africa, the balistes bloom has been equally remarkable even though the estimated potential is not yet fully exploited. Also the three Pacific Basin populations of sardines have flown in the face of all theory by exploding their numbers and colonizing old and new habitats, all in spite of intense fishing activities. Like all such phenomena, the questions far outnumber the answers. As a prelude to these changes there have been notorious fishery collapses, with all the associated finger pointing and babbling over why management failed to "save" that fishery. A question needing to be answered is whether conventional management could have been able to prevent the resource collapse, and in either case, whether it could have changed anything regarding the fishery's failure and its impact on the national economies and society?

This Expert Consultation is a timely follow-on to many related regional or topical symposiums, workshops and research programmes that had been channeling the attention of the scientific community towards a more comprehensive approach to fisheries sciences, resources variability, its cause and consequences. Listing them all will be impossible, therefore, we will only refer to those scientific events that more directly have influenced this consultation. Starting from the ICES Symposium on the Assessment and Management of Pelagic Fish Stocks in Aberdeen in 1978; the Lima Workshop on the Effects of Environmental Variation on Survival of Larval Pelagic Fishes; and the ICANE review of joint Canadian-Peruvian research into the finer scales and highly dynamic nature of the Humboldt Current off Peru. Also the IOC Resolution XI-17 has provided stimulus for FAO to give appropriate consideration to the topic of Ocean Science in Relation to Living Resources (OSLR) in international contexts.

Who should be responsible for managing fishery resources, and what information is needed if catch statistics alone, if available at all, cannot be used to forecast either blooms or recessions of major fishery resources? Who should be responsible for the societal burdens upon collapse of a fishery? Should the industry and investors always be the major winners in the cycle of bloom and recession; receiving low cost loans or subsidies for initial investments, and being given tax relief or even benefitting from buy-back schemes when the economic returns decline or become negative during poor periods? The fishermen and shore-based support facilities and labour forces are too often left holding an empty bag, the profits having been exported along with the catches. It appears that in fisheries based on volatile bloom and recession based resources, it pays to lose if you are an early investor. The taxpayers will be passed the bills for initial investments as well as the relief programmes after a collapse occurs.

Of course all this takes place behind the smoke-screens provided by the continuous speculations of various "experts" on what could or should be done to "rationalize" the fisheries once the declines are noted. Numerous examples of typical future exercises are provided in these Proceedings, in which the tug-of-war between Industry, Fishery Science and Politics is resolved only by the collapse of another resource. The onus is always on the "Scientist" to prove his position, rather than upon Industry, whose position is usually simply to take short-term gains and move on. It appears to be a huge tragic-commedy in which the self-righteous scientist is the goat, the fisherman and national taxpayers are the losers, and the exporters and outside investors usually remain anonymous winners.

One should not feel too much sympathy for fishery scientists who are too limited in their approach to measuring and monitoring the dynamic Oceans and their living contents. Some large fraction of fishery scientists appear content with giving only partial answers based on their conventional wisdoms and methods. That these might be completely inadequate or even inappropriate to the task is rarely an issue among them. Just what information is needed to cope with varying resources? This is what this Expert Consultation was about, and we are certain that answers will be found in the contributions produced for, and the Reports produced from the Expert Consultation. All contributions that were accepted for presentation are included in this volume either in full or in summary form.

The reports produced from the consultation are incorporated in the Report of the Expert Consultation, published in the first volume of this FAO Fisheries Report No. 291.

Most of the participants in this consultation were chosen because they are moving in directions which we thought will contribute and extend our abilities to measure, monitor and assess the impacts of system perturbations on resource populations. We can only lament the fact that we could not have included more of the front line fishery research community, but facilities and time were limiting. In any case we are certain that the fisheries community will appreciate the efforts that these contributions represent. We are quite content that we were able to facilitate this gathering as well as the timely publication and dissemination of the contributions.

## Purpose and organization

The Expert Consultation to Examine Changes in Abundance and Species Composition of Neritic Fish Resources was held in San José, Costa Rica, from 18 to 29 April 1983 at the kind invitation of the Government of Costa Rica. In total 58 participants and 13 observers attended the consultation. The list of participants is attached.

The consultation was organized by FAO as part of the preparations for the FAO World Conference on Fisheries Management and Development and as a contribution to the Programme on Ocean Science in Relation to Living Resources adopted by the Intergovernmental Oceanographic Commission (IOC).

The central theme of the consultation was the variability of neritic fish resources. The detailed objectives were:

- To document the changes that have occurred, in each region, in the environment, the abundance and distribution of fish populations, and in the fisheries, including societal and economic effects.

- To identify decision-makers' objectives and document how these are affected by changes in fish stocks.

- To provide an opportunity for comparison between regions, and to establish the similarities and differences, as a basis for improved understanding of the events in each individual region.

- To promote the inter-disciplinary study of the neritic systems, bringing together experts in the fields of oceanography and meteorology; basic biology; fishing industry; resource assessment and monitoring; and fishery management.

- To increase the understanding of the general processes involved in the dynamics of pelagic fisheries, which may lead to improved ability to predict significant changes in the system, hence to allow more time and options for the decision-making process.

- To provide a better scientific basis for the development of a management strategy which will take account of the best current knowledge, as well as the possibility of large-scale changes in the natural system.

The Expert Consultation took place in two phases. The first week was characterized by Symposium-type presentations. The technical secretaries opened the technical presentations by introducing the general topic of the neritic environment, the changes exhibited by living marine resources in these complex systems and the scientific and management problems that arise as fishery resources respond to the continuous barrage of environmental and biological changes, natural and man-induced.

Presentation and discussion of 53 background and review papers followed. These presentations were grouped into four sessions that covered:

(1) reviews of major neritic fish resources around the world where environmental and resource changes and related fishery responses were described;

(2) localized and comparative studies of environmental changes which included local studies as well as ocean scale and regional comparisons;

(3) review of impacts of environmental and resource variability on human communities; and

(4) application of methods and theory in fisheries and related fields.

Volumes 2 and 3 of this FAO Fisheries Report give a full account of the papers that were presented in the first week of the Expert Consultation.

A round table was also organized during the first week to hold informal discussions on objectives of fisheries management and decision-making processes. This informal session was chaired by M.H. Glantz and was formed comprising various interest groups available among the participants, i.e. industry scientists; international investment bank representatives; fishery managers; multinational fish buyer-processors; social scientists; and fisheries biologists. Short statements were made of the kinds of information each considered to be important to their specific decision-making. This produced a broader dialogue and emphasized some of the conflicts of interest characterizing the different factions involved in fishery decision-making.

Four Working Groups were set up during the second week, each one dealing with a particular subject on which a report was drafted. Sessions of Working Group No. 1 were chaired by Alec MacCall; this group discussed and drafted a report on resources study and monitoring. Sessions of Working Group No. 2 were chaired by Michael H. Glantz; this group discussed and drafted a report on societal and economical implications of varying fishery resources. Sessions of Working Group No. 3 were chaired by Andrew Bakun; this group discussed and drafted a report on environmental studies and monitoring. Sessions of Working Group No. 4 were chaired by Jorge Csirke; this group discussed and drafted a report on fisheries management, implications and interactions.

## Results

Main results of this Expert Consultation are reflected by the reports of the four working groups. These reports constitute the Report of the Expert Consultation and are being published in the FAO Reports Series as FAO Fisheries Report No. 291, Volume 1.

The report of Working Group No. 1 on Resource Study and Monitoring sets up major guidelines to study and monitor variable fisheries resources, providing information which may be useful in evaluating needs and choosing among alternative methods and studies. The report also identifies major symptoms of adverse changes (and potential collapse) in resource status and discusses a variety of topics on monitoring of fishery operations and biological sampling.

The report of Working Group No. 2 on Societal and Economical Implications of Varying Fishery Resources identifies the different effects the variability of fisheries resources has on society, identifies different groups (at the individual, national and international level) that play a role in the decision-making process and those sectors that are more seriously affected by resources fluctuations. The report also discusses the way some fisheries had developed in the past, sources of problems related to fisheries management, the participation of fisheries scientists in the decision-making process, the problems that confront fisheries scientists in this process and suggests some remedies for dealing with such problems.

The report of Working Group No. 3 on Environmental Studies and Monitoring identifies the main "primary variables" or conditions which directly affect individual fish, and through these populations abundance. These primary variables (i.e. food, production, temperature, salinity and oxygen concentration) are altered by several processes, some of which are described in the report together with the different sources of information on environmental variability and biological characteristics. The report stresses the need for more rigorous approaches to the problem of environmental effects on fishery problems and makes some suggestions in this respect. It also underlines the value of having information on environmental variations for management purposes, particularly when environment has proven to be a major source of fluctuation of fish availability.

The report of Working Group No. 4 summarizes the results of the other three working groups as they apply to Fisheries Management. In this report it is recognized that variability in recruitment is the major immediate cause of the fluctuations in the neritic fish resources, which in most cases seems to be closely linked with changes in environmental conditions. However, it also recognizes that fishing has also played a major part in exaggerating these fluctuations and in precipitating the collapse of a number of pelagic fisheries. In highly variable resources the level of biomass or production cannot be regulated by varying fishing effort. However, because of the higher risks of collapse and the economic and societal costs involved, the needs for management are greater when dealing with these highly variable resources.

The traditional approach to fisheries management tends to concentrate on managing the resources and its fluctuations primarily by regulating timing and amount of fishing. Working Group No. 4, recognizing that variability is an inherent characteristic of many neritic fish populations, suggests that management efforts should be concentrated on managing fisheries and their fluctuations by following, or better, by anticipating resources fluctuations. The report stresses that when managing fisheries of highly variable resources one of the objectives is to not aggravate resource fluctuations, and to conduct the developments of the fishery in such a way as to maximize gains in periods of great abundance and minimize losses during periods of lowest abundance. A higher degree of flexibility needs to be introduced in the fleets, industries, factories, marketing processes, etc., in order to allow the fisheries sector to buffer the effects of the fluctuations and adapt quickly to possible changes of the resources.

These proceedings reflect the efforts and experiences of many people, all of whom have been or are involved directly or indirectly in fisheries and fishery related problems. This we think is the best indication of the relevance of this volume to future research requirements, future social and societal assessments and particularly to future management practices. We suggest that both these Proceedings and the Report of the consultation be considered as complementary to each other. They should be read and studied as such when trying to wheigh past, present and future management practices and procedures.

## INTRODUCCION Y RESUMEN DE LA CONSULTA DE EXPERTOS

Los casi cien años de avances en el campo de la ciencia pesquera han contribuido significativamente a la formulación de las bases científicas existentes para determinar medidas de ordenación y administración de la pesca. Sin embargo, eventos recientes que han afectado el clima marino y la producción biológica en amplias zonas del Océano Atlántico y el Océano Pacífico, han hecho que muchos científicos y administradores de la pesca cambien sus puntos de vista acerca de los recursos de peces neríticos y de lo que de ellos se puede esperar. Esto, por cierto, crea la demanda de nuevos y mejores métodos y teorías para tratar con estos recursos.

En algunas áreas donde existen pesquerías altamente desarrolladas y complejas, como en el Atlántico y Pacífico norte por ejemplo, los recursos y la pesca se investigan y monitorean periódicamente para poder planear e implementar medidas de ordenación más o menos elaboradas. Hay sin embargo, muchas otras áreas donde la información que se requiere para adoptar medidas de ordenación es insuficiente o, simplemente, no es costumbre basarse en la información científica para administrar las pesquerías.

Ciertamente se puede argumentar que tanto las bases para la ordenación de la pesca así como la información necesaria para implementarla tenderán a evolucionar y a desarrollarse en la medida en que éstas se hagan necesarias. Sin embargo, si revisamos la efectividad de las medidas típicas de ordenación de la pesca aplicadas en muchas pesquerías, encontraremos que precisamente cuando la ordenación se hacía más necesaria, los resultados que se han obtenido han sido pobres e inclusive se ha contribuido a estimular la competencia excesiva, la sobreexplotación, la drástica disminución del recurso o el fracaso económico de la pesquería. Hay numerosos ejemplos de este tipo de resultados y en este volumen se han documentado algunos casos.

El principal defecto de muchos de los instrumentos y métodos para medir y monitorear disponibles en pesquería es que tienden a integrar las variaciones generando valores y expectativas promedios que no son suficientemente conservadoras durante períodos de reducción del recurso y, por otro lado, tienden a subestimar lo que está ocurriendo en períodos de expansión o crecimiento. Los métodos y modelos basados en el concepto del "estado de equilibrio" han sido y son útiles en muchas pesquerías, pero han mostrado ser inadecuados cuando se trata de recursos altamente variables y dinámicos que en definitiva no hacen sino reflejar los cambios de sistemas ecológicos más grandes y complejos y de procesos relacionados que son inducidos por el clima y el ambiente oceánico. Estos a su vez son sumamente difíciles de medir y pronosticar. Hay una serie de cambios ambientales que pasan desapercibidos a los instrumentos y sistemas de monitoreo tradicionales y frecuentemente estos cambios tienen efectos más o menos importantes sobre las pesquerías y los recursos pesqueros; lógicamente en estos casos se reduce el alcance de los posibles pronósticos con la consecuencia de que las alternativas disponibles a los administradores de la pesca quedan limitadas a reacciones en plazos muy breves que, si es que se llega a producir alguna reacción, tienen que estar basados en pronósticos a breve término y cobertura espacial limitada.

Inclusive la aplicación del concepto de "equilibrio" a períodos de breve tiempo, donde se asume que algunos parámetros claves pueden mantenerse constantes, contrasta con eventos recientes en algunas de las principales zonas neríticas. Por ejemplo, al noroeste de Africa la abundancia y la pesca de cefalópodos han aumentado en forma que no tiene precedentes; en Africa ecuatorial el crecimiento explosivo de balistes ha sido igualmente notable, aun cuando todavía no se está explotando todo el potencial estimado. Las tres poblaciones de sardina de la cuenca del Océano Pacífico han crecido explosivamente desafiando la teoría existente, han aumentado en número y en área de distribución colonizando habitats antiguos y nuevos, y todo esto a pesar de la intensa actividad pesquera a que están expuestos. Como en todos los fenómenos de este tipo, el número de preguntas excede ampliamente al de las respuestas. Como preludio a estos cambios se han producido colapsos con la consiguiente proliferación de imputaciones y polémicas sobre por qué los responsables de la ordenación de la pesca no cumplieron con salvar esa pesquería. En estos casos una de las interrogantes que necesita una respuesta se refiere a si es que las medidas convencionales de ordenación y manejo habrían podido prevenir el colapso del recurso y, en cualquier caso, si es que habría sido posible cambiar algo con respecto a la quiebra de las pesquerías y sus impactos en la economía nacional y en la sociedad.

Esta Consulta de Expertos constituye una oportuna continuación de una serie de simposios, reuniones de trabajo y programas de investigación que actuando a nivel nacional, regional o internacional han ido canalizando la atención de la comunidad científica hacia un enfoque más amplio en el campo de las ciencias pesqueras, la variabilidad de los recursos, sus causas y consecuencias. Mencionar todos sería imposible, por lo tanto sólo nos vamos a referir a algunos eventos científicos que en forma más directa han influenciado esta Consulta. Cabe citar el simposio de ICES sobre Evaluación y Manejo de Stocks de Peces Pelágicos que se realizó en Aberdeen en 1978; la reunión conclusiva del Proyecto de Investigación Cooperativa de la Anchoveta y su Ecosistema (ICANE) entre Perú y Canadá, realizada en Lima en 1979; el Taller de la FAO sobre los Efectos de la Variación Ambiental en la Sobrevivencia de Larvas Pelágicas de Peces, realizado en Lima en 1980. También la resolución XI-17 de la COI ha estimulada a la FAO a dar adecuada consideración al tema de Ciencias Oceánicas en Relación con los Recursos Vivos (OSLR) en el contexto internacional.

¿Quién debe ser el responsable de la ordenación de los recursos pesqueros y cuál es la información que se necesita si las estadísticas de la pesca, si es que existen, no pueden ser utilizadas por sí sólas para pronósticar la expansión o colapsos de los principales recursos pesqueros? ¿Quién debe soportar las cargas sociales generadas por el colapso de una pesquería? ¿La industria y los inversionistas deberían seguir siendo los principales beneficiarios de los ciclos de aumento y disminución de los recuros pesqueros, recibiendo préstamos a bajo interés o subsidios para la inversión inicial y recibiendo compensaciones tributarias o inclusive beneficios de programas de compra de infraestructura excedente, cuando la retribución económica disminuye o se hace negativa en períodos de crisis en la pesca? Cuando colapsa una pesquería, no es raro que los pescadores, quienes proveen servicios de apoyo en tierra y los trabajadores queden con las manos vacías, luego que las ganacias han sido exportadas junto con las capturas. Aparentemente cuando se trata de pesquerías basadas en recursos inestables que aumentan y disminuyen rápida y marcadamente, vale la pena perder si se está entre los primeros inversionistas. Los contribuyentes son lo que terminan pagando la cuenta de las inversiones iniciales, y de los programas de asistencia una vez que la pesquería colapsa.

Por cierto todo esto suele ocurrir detrás de una cortina de humo, donde abundan las especulaciones de los varios "expertos" sobre qué cosa se podría o se debería hacer para "racionalizar" la pesquería una vez que la declinación de las capturas y los rendimientos son evidentes. En estas actas se presentan algunos ejemplos de esta clase de ejercicios, donde los enfrentamientos entre sectores de la industria, la ciencia pesquera y la política se han resuelto con la sobreexplotación y eventual colapso de algún otro recurso. El científico es siempre puesto bajo la presión de tener que probar que su posición es correcta, mientras que esto no se hace con la industria, cuya posición normalmente es la de obtener beneficios a corto plazo y continuar operando. Parece como si fuera una comedia trágica, en la cual el riguroso científico es el chivo expiatorio, los pescadores y contribuyentes son los perdedores, y los exportadores e inversionistas normalmente permanecen como vencedores anónimos.

Sin embargo, no debería uno sentir mucha simpatía por los científicos pesqueros que tienen un enfoque muy limitado al tratar de medir y monitorear la dinámica de los océanos y su contenido de seres vivientes. Una amplia proporción de científicos pesqueros parecen quedar satisfechos con dar sólo respuestas parciales basadas en sus métodos convencionales, y raramente ponen en discusión el hecho de si estos métodos y técnicas son realmente adecuados o apropiados para los fines que deberían estar persiguiendo. Esta Consulta de Expertos trata el tema de qué tipo de información es la que se necesita para hacer frente a la situación derivada de explotar recursos que son altamente variables, y estamos seguros que en las contribuciones producidas para esta Consulta y los informes producidos por esta Consulta se encontrarán respuestas a muchas de estas preguntas. Todas las contribuciones que fueron aceptadas para su presentación en Costa Rica han sido incluidas en este volumen ya sea con su texto total o en forma resumida.

Los informes producidos como resultado de la reunión están incorporados en el Informe de la Consulta de Experto publicado en el primer volumen del FAO Informes de Pesca No. 291.

La mayor parte de los participantes en esta Consulta fueron seleccionados por estar trabajando activamente en campos que creemos contribuirán a extender nuestra habilidad para medir, monitorear y evaluar el impacto de las perturbaciones de los distintos sistemas sobre las poblaciones de peces. Si de algo debemos lamentarnos es de no haber podido incluir más representantes de primera línea de la comunidad científica, pero las facilidades y el tiempo eran un factor limitante. En todo caso, estamos seguros que la comunidad científica relacionada con la pesca apreciará los esfuerzos que estas contribuciones representan. Estamos también muy satisfechos de haber tenido la posibilidad de realizar esta reunión, así como la publicación en tiempo bastante breve y distribución de estas contribuciones.

## Fines y organización

La Consulta de Expertos para Examinar los Cambios en la Abundancia y Composición por Especies de Recursos de Peces Neríticos se llevó a cabo en San José, Costa Rica, del 18 al 29 de abril de 1983 por gentil invitación del Gobierno de Costa Rica. En total 58 participantes y 13 observadores asistieron a la Consulta. La lista de participantes está adjunta. La Consulta fue organizada por la FAO como parte de los preparativos para la Conferencia Mundial sobre Ordenación y Desarrollo de la Pesca de la FAO, y como contribución al programa sobre Ciencias Oceánicas en Relación a los Recursos Vivos adoptado por la Comisión Oceanográfica Intergubernamental (COI).

El tema central de la Consulta fue la variabilidad de los recursos de peces neríticos. Los objetivos específicos fueron:

- Documentar los cambios que han ocurrido en cada región en las condiciones ambientales, en la distribución y abundancia de las poblaciones de peces y en la pesquería, incluyendo los efectos sociales y económicos.

- Identificar los objetivos de los niveles de decisión y documentar como son afectados por los cambios en las poblaciones de peces.

- Dar oportunidad para hacer una comparación entre regiones, y establecer las semejanzas y diferencias como una base para mejorar el entendimiento de los eventos que ocurren en cada región.

- Promover el estudio interdisciplinario de los sistemas neríticos, reuniendo expertos en los campos de oceanografía y metereología, biología básica, industria pesquera, evaluación y monitoreo, y ordenación de pesquerías.

- Mejorar el conocimiento de los procesos involucrados en la dinámica de las pesquerías pelágicas, lo que puede conducir a una mejor capacidad de predecir cambios significativos en el sistema, permitiendo así un aumento del tiempo y alternativas disponibles en el proceso de toma de decisiones.

- Proporcionar una mejor base científica para el desarrollo de una estrategia de ordenación y manejo que tome en consideración lo mejor del conocimiento actual, así como la posibilidad de cambios de gran escala en los sistemas naturales.

La Consulta de Expertos se llevó a cabo en dos fases. La primera semana se caracterizó por presentaciones tipo simposio. Los secretarios técnicos iniciaron las presentaciones técnicas introduciendo el tema general del ambiente nerítico, los cambios mostrados por los recursos vivos marinos en estos complejos sistemas y los problemas científicos y de ordenación que surgen a medida que los recursos pesqueros responden al continuo bagaje de cambios ambientales y biológicos que ocurren tanto por causas naturales como inducidos por el hombre.

Luego de esta sesión de introducción se presentaron y discutieron 53 trabajos de revisión y antecedentes relacionados con las pesquerías neríticas. Estas presentaciones fueron agrupadas en cuatro sesiones de acuerdo a los siguientes temas centrales:

1) revisión de los principales recursos neríticos alrededor del mundo, donde se describen cambios ambientales y en los recursos así como reacciones de la pesca;

2) estudios comparativos y localizados de cambios ambientales donde se incluyen estudios locales, así como estudios de escala oceánica y comparaciones regionales;

3) revisión de los impactos de la variabilidad del ambiente y los recursos sobre las comunidades humanas; y

4) la aplicación de métodos y teorías en pesquería y en campos relacionados.

Estas actas dan cuenta de todos los documentos que fueron presentados en la primera semana de la Consulta de Expertos.

Durante esta primera semana también se organizó una mesa redonda para discutir a nivel informal los objetivos de la ordenación y administración de la pesca y los procesos en la toma de decisiones. Esta sesión informal fue presidida por M.H. Glantz y fue conformada por representantes de varios de los sectores o grupos de interés presentes entre los los participantes. Participaron tanto científicos de la industria, representantes de bancos e inversionistas, administradores de la pesca, expertos en procesamiento y mercadeo de pesca, sociólogos y biólogos pesqueros. En esta sesión cada participante hizo una breve presentación de los tipos de información que en cada caso se consideran importantes para la toma de decisiones. Esto generó un amplio diálogo y puso en evidencia algunos de los conflictos de intereses que caracterizan los distintos sectores involucrados en el proceso de toma de decisiones en pesquería.

Durante la segunda semana se formaron cuatro grupos de trabajo, donde cada grupo trató un tema particular sobre el cual se preparó un borrador de informe. Las sesiones del Grupo de Trabajo Nº 1 fueron presididas por Alec MacCall; este grupo descutió y preparó un borrador de informe sobre el estudio y monitoreo de recursos pesqueros. Las sesiones del Grupo Nº 2 fueron presididas por Michael H. Glantz; este grupo discutió y preparó un borrador de informe sobre los efectos sociales y económicos de la variabilidad de los recursos pesqueros. Las sesiones del Grupo de Trabajo Nº 3 fueron presididas por Andrew Bakum, este grupo discutió y preparó un borrador de informe sobre la investigación y monitoreo del ambiente. Las sesiones del Grupo de Trabajo Nº 4 fueron presididas por Jorge Csirke; este grupo discutió y preparó un informe sobre la ordenación pesquera, sus implicancias e interacciones.

## Resultados

Los principales resultados de esta Consulta de Expertos estan contenidos en los informes de los cuatro grupos de trabajo. Estos informes constituyen El Informe de la Consulta de Expertos y están publicados en FAO Informe de Pesca Nº 291, volumen 1.

El informe del Grupo de Trabajo Nº 1 sobre Investigación y Monitoreo de Recursos da lineamentos generales para estudiar y monitorizar recursos pesqueros variables, proporcionando información que puede ser útil en la evaluación de necesidades y en la selección de métodos y estudios alternativos. Este informe también identifica los principales síntomas de cambios adversos (y potencial colapso) de los recursos pesqueros, y discute una variedad de aspectos relacionados con el monitoreo de operaciones pesqueras y muestreos biológicos.

El informe del Grupo de Trabajo Nº 2 sobre Implicaciones Sociales y Económicas de la Variabilidad de Recursos Pesqueros identifica los diferentes efectos que tiene la variabilidad de los recursos pesqueros en la sociedad, identifica los diferentes grupos (a nivel individual, nacional e internacional) que juegan un rol en el proceso de toma de decisiones e identifica también aquellos sectores que son afectados más seriamente por las fluctuaciones de los recursos. Este informe también discute la forma como algunas pesquerías se han desarrollado en el pasado, la causa de los problemas relacionados a la ordenación de la pesca, la participación de científicos pesqueros en el proceso de toma de decisiones y los problemas que tienen que afrontar los científicos pesqueros en este proceso. Sugiere también algunos remedios para tratar con estos problemas.

El informe del Grupo de Trabajo Nº 3 sobre Estudios Ambientales y Monitoreo identifica las principales variables primarias o condiciones que más directamente afectan al pez individualmente y a través de esto la abundancia de las poblaciones. Las variables primarias (tales como alimento, producción, temperatura, salinidad y concentración de oxígeno) son alterados por varios procesos, algunos de los cuales se describen junto con las diferentes fuentes de información sobre variabilidad ambiental y caracteristicas biológicas.

El informe hace énfasis en la necesidad de un enfoque más riguroso para abordar el problema de los efectos ambientales en relación a los problemas pesqueros y hace algunas sugerencias a este respecto. El informe también subraya el valor de tener información sobre variabilidad ambiental para los fines de ordenación y manejo de la pesca, particularmente cuando el ambiente ha probado ser una causa principal de la fluctuación en la disponibilidad de peces.

El informe del Grupo de Trabajo Nº 4 resume los resultados de los otros tres grupos de trabajo en la medida en que éstos se aplican en la ordenación de la pesca. En este informe se reconoce que la variabilidad del reclutamiento es la principal causa inmediata de la fluctuación de los recursos de peces neríticos, cuya variación en la mayoría de los casos parece estar estrechamente relacionada con cambios en las condiciones ambientales; pero también se reconoce que la pesca ha jugado un papel importante al exagerar estas fluctuaciones y precipitar el colapso de una cantidad de pesquerías pelágicas. En el caso de recursos altamente variables, el nivel de biomasa o producción no puede ser regulado variando simplemente el esfuerzo de pesca; sin embargo cuando se trata de este tipo de recursos, las necesidades de ordenación y manejo de las pesquerías son mucho mayores debido al alto riesgo de colapso y los costos económicos y sociales involucrados.

En su enfoque tradicional, la ordenación de la pesca tiende a concentrarse en tratar de manipular los recursos y sus fluctuaciones, principalmente regulando el tiempo y cantidad de pesca. El Grupo de Trabajo Nº 4 reconoce que la variabilidad es una característica inherente a muchos recursos de peces neríticos y sugiere que los esfuerzos de ordenación y de manejo deben concentrarse en las pesquerías y sus fluctuaciones, siguiendo o mejor aún anticipando la fluctuación de los recursos. El informe hace incapié en que cuando se trata de ordenar las pesquerías de recursos altamente variables, uno de los objetivos es tratar de no agravar la fluctuación de los recursos y conducir el desarrollo de la pesquería de tal forma que permita maximizar las ganancias en períodos de gran abundancia y minimizar las pérdidas en períodos de baja abundancia. Se sugiere la necesidad de introducir un mayor grado de flexibilidad en las flotas, las industrias, las factorías, los procesos de mercadeo, etc., con la finalidad de permitir que el sector pesquero pueda amortiguar los efectos de las fluctuaciones y se pueda adaptar más rápidamente a posibles cambios en los recursos.

Estas actas refejan los esfuerzos y experiencias de mucha gente proveniente de campos diversos y que representan algunos de los principales grupos de interés relacionados con la ciencia pesquera y la ordenación de la pesca. Esperamos que esta obra contribuya a una mejor definición de los futuros requerimientos en el campo de la investigación, las evaluaciones de los efectos sociales, y particularmente de la puesta en práctica de medidas de ordenación de la pesca. Tanto que estas actas como el informe de la Consulta de Expertos son complementarios, y sugerimos que sean estudiados y revisados como tales cuando se trate de sopesar las prácticas y normas de ordenación de la pesca pasadas, presentes y futuras.

## LIST OF PARTICIPANTS
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# PART I - REGIONAL REVIEWS DESCRIBING ENVIRONMENTAL RESOURCES CHANGES AND RELATED FISHERY RESPONSES

# PARTE I - ANALISIS REGIONALES DE LOS CAMBIOS EN EL MEDIO AMBIENTE Y EN LOS RECURSOS Y DE LAS CORRESPONDIENTES REACCIONES EN EL CAMPO DE LA PESCA

*NORTH WEST PACIFIC AND SEA OF JAPAN – PACIFICO NORDOCCIDENTAL Y MAR DEL JAPON*

# VARIATION OF PELAGIC FISH STOCKS IN WATERS AROUND JAPAN

by

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## Resumen

La plataforma continental alrededor de Japón es angosta y los de peces de fondo son relativamente poco abundantes. Por el contrario, los peces pelágicos son abundantes gracias a las zonas de frentes donde las corrientes frías entran en contacto con las corrientes cálidas, y las pesquerías de peces pelágicos estan bien desarrolladas. En Japón la captura total de peces pelágicos que se alimentan de plancton de aguas cálidas ha aumentado contínuamente desde 2 millones de toneladas hasta 3 millones de toneladas en el período de 1952 a 1975. Las capturas de sardinas aumentaron dramáticamente y la captura total alcanzó 4.7 millones de toneladas en 1981. La captura de estas especies ocupa 30 a 50% de los desembarques totales de peces marinos de Japón. Las capturas de especies individuales muestran una gran variabilidad, las principales especies dominantes cambian con frecuencia. El coeficiente de variación de las capturas es menor del 30% para calamar y anchoveta, alrededor del 50% para saury, jurel y caballa, y es mucho más alto, alrededor de 150%, para sardina. Estos peces pelágicos generalmente desovan en aguas costeras en la corriente cálida de Kuroshio frente al sudeste de Japón en invierno y primavera. Estos se alimentan en las zonas de los frentes del norte en verano y otoño. Las áreas de pesca se forman tanto en las áreas de desove como en las áreas de alimentación. Se cree que el tipo de ruta que sigue la corriente de Kuroshio y sus cambios bruscos tienen una relación estrecha con los cambios en el tamaño de los stocks.

Los índices de abundancia relativa de los stocks de saury en el Océano Pacífico Noroeste fueron cálculados a partir de datos de captura y esfuerzo, y se encontró que la abundancia no fluctúa tan ampliamente como fluctúa la captura. La captura disminuyó a fines de los años 1960s mientras que la intensidad de pesca disminuyó continuamente desde fines de los años 1950s. La relación entre la abundancia del stock desovante y el reclutamiento no está clara. El tamaño de los stocks es determinado por el suceso o fracaso de la reproducción anual. La captura del arenque de Hokkaido fue mayormente hecha en base a las clases anuales dominantes que aparecen cada cierto número de años. El análisis de la relación entre el stock desovante y el reclutamiento revela que en los años 1930s y 1940s no apareció ninguna clase dominante, a excepción de la clase anual de 1939, aun cuando el número de individuos adultos no era pequeño. La comparación de la abundancia de huevos y reclutamiento para el stock de caballa del Pacífico indican que las clases anuales relativamente grandes fueron producidas a partir de abundancias pequeñas de desovantes entre 1954 y 1957 y el stock comenzó a expandirse. La sardina disminuyó dramáticamente a fines de los años 1930s, probablemente debido a una mortalidad masiva de larvas causada por las aguas frías que ocurrieron al sur de Honshu. Análisis de las estadísticas de capturas sugieren que la falta de reclutamiento fue la causa del colapso. Ha habido algunos intentos para explicar la alternancia en la dominancia de especies en base a la interacción entre especies, pero la evidencia directa es pobre. Se piensa que los cambios de las condiciones oceanográficas tienen algún efecto en este fenómeno. Algunas interacciones no lineares entre las especies pueden explicar bien este fenómeno.

Muchos aspectos indican que los cambios de los stocks de peces pelágicos fueron causados por variación del reclutamiento. No se ha presentado ninguna evidencia de sobrepesca. La pesquería de peces pelágicos debe tener una constitución bien adaptada a la variabilidad de los stocks. Un sistema para utilizar en forma integral toda la comunidad de peces debe ser desarrollada. La predicción de las condiciones futuras de los stocks es necesaria. Los sistemas de licencias como medida para limitar el esfuerzo de pesca pueden ser efectivos. La protección de peces inmaduros es deseable para asegurar la abundancia de huevos.

## INTRODUCTION

The continental shelf around Japan is narrow except in the West China Sea and the abundance of ground fishes is rather small. On the contrary, pelagic fishes are abundant due to complicated oceanographical conditions, and there are various kinds of fisheries for pelagic fishes. The Kuroshio (warm current) approaches to Japan from the south and flows eastward along the southern coast of Japan and meets with the Oyashio (cold current) which comes down from the north along the Kurile, Hokkaido and northern Honshu. A branch of the Kuroshio enters into the Sea of Japan (Tsushima Current) and meets with cold water masses in the northern part of the sea. Frontal zones and mixing zones are formed in the areas where the cold currents and the warm currents contact.

Pelagic fishes are characterized by a large variability of their stocks. The saury catch showed a large year to year fluctuation depending on oceanographical conditions of the year as will be explained in this paper. Sardine stocks repeated very large variations with a long period of several decades or longer. This periodical change has been found by Uda (1952) when he examined historical documents. According to the data summarized by Ito (1961), the first record on a good catch of sardine appeared in the period of 1558-1569 and again 1573-1591 in the Sea of Japan. In 1624-1643 period, however, a poor catch was reported in the western Sea of Japan. After these records, nationwide trend of good and poor catches were recorded repeatedly; good catch in 1690-1720, poor catch in 1750-1760, good catch in 1790-1830, and poor catch in 1840-1910. In recent years, the catch was very high from 1930 to 1942 reaching a maximum of 1.6 million tons, very low from 1960 to 1972 recording a minimum of only 9,000 tons in 1965. After 1975, a very high catch is being recorded every year. The Hokkaido herring also showed a large long term variation. At the end of the 19th century the highest catch of almost one million tons was recorded, by 1960 this stock virtually disappeared.

As the catches fluctuate in short term and also in long term, prediction of future catch of pelagic fishes is an important subject. Studies on fisheries biology in Japan in the 1930's and 1940's were concentrated on short term fluctuations of catches particularly on the relation between the distribution and movement of fish and oceanographical conditions. Many papers have been published on formation of fishing grounds in relation to distribution of frontal zones (shiome) and water masses (e.g. Uda, 1936a; b; Kimura, 1956).

The core of the Japanese fishery management has depended on a licence system since long ago. As the majority of the catch comprises pelagic fishes which show considerable variations, not much importance was placed on other measures than regulation of the number of boats by issuing licences such as catch limit, size limit and mesh size regulation. This circumstance is quite different from that prevailing in Europe and North America where fisheries aim mostly at ground fishes. Although individual species fluctuate greatly, it seldom happens, as will be explained, that many species maintain very high levels simultaneously or all of species are kept at low levels at the same time. Collapse of one species is usually compensated by building up of some other species. The diversity in demand on fisheries products easily accommodates changes in the dominant species, and together with subsidies from the government and a feeling of stability caused by the licence system, the Japanese fisheries have enjoyed their prosperity regardless of changes of species.

In this paper firstly fluctuations of the catch of pelagic fishes in waters around Japan are described and general patterns of life history of fishes are described. Then some results of studies on the dynamics of several species of fishes are introduced. Finally some discussions on the basic principle of the management of pelagic species with high variability are presented.

# PELAGIC FISHES IN WATERS ADJACENT TO JAPAN

## Changes of catches

Important neritic-pelagic species in waters around Japan include warm water species such as sardine *Sardinops melanosticta*, anchovy *Engraulis japonica*, round herring *Etrumeus teres*, mackerel *Scomber japonicus* and *S. tapeinocephalus*, jack mackerel *Trachurus japonicus*, saury *Cololabis saira*, yellowtail *Seriola quinqueradiata*, and flying squid *Todarodes pacificus*, and cold water species of herring *Clupea pallasi*. Besides these, oceanic species such as tuna, skipjack and salmon occur in quantities. Here, these oceanic fishes will not be dealt with further. Although yellowtail is a neritic species this is a large sized fish eater. The catch is fairly constant being 27,000- 55,000 tons with the average of 44,300 tons since 1960. Recently aquaculture of this species by raising juvenile fish up to a good size has been developed and the production has reached 150,000 ton level and far exceeds the catch from the sea.

All of above mentioned warm-water neritic species except yellowtail have characteristics in common that they are plankton feeders and inhabit in waters under the influence of the Kuroshio. They are important as their catches are very large. The total catch of these warm-water plankton-feeding fishes since 1930 are illustrated in Fig. 1. In the 1930's the sardine stock flourished and the total catch approached to 2 million ton level but it suddenly declined in the early 1940's, and the war further hindered the fisheries and the catch dropped to a minimum in 1945. Immediately after the war, the catch began to increase and recorded 2 million tons in 1952. Then it grew gradually and reached to 3 million ton level around 1975.

In the late 1970's, sardine catch started a dramatic revival while mackerel catch was still kept at a high level of more than 1 million tons. The total catch in 1981 was surprisingly high at 4.7 million tons. The total catch of these species occupied 30% of more of the total catch of the marine fisheries and are always very important for the Japanese fisheries (Fig. 1). The proportions of these species dropped a little in the late 1960's and the early 1970's. This is due to a large catch of Alaska pollock in Alaskan and Siberian waters. Within the waters adjacent to Japan, these species continued to occupy more than 30%. It should be noted that the total catch was relatively stable being between 2 to 3 million tons since 1930 except the war time and after 1977. This stability was realized while the catches of individual species varied considerably.

In and after 1952 when sardine and anchovy catches are recorded separately in the statistics, the catches of each species are presented in Fig. 2. In this figure, mackerel includes both *S. japonicus* and *S. tapeinocephalus* but the former predominates in the catch. After 1945, the last year of the war, the catch of squid increased sharply from 100,000 ton level to 500,000 ton level. Then saury showed a good catch in the late 1950's, jack mackerel did the same in the early 1960's, and the catch of each species was maintained at a level of a half million tons for several years. Decreasing trend became obvious for saury since 1964 and for jack mackerel since 1967. Mackerel catch was in an increasing trend since 1950 and the trend was accelerated in the 1960's substituting poor catches of saury and jack mackerel. The catch has been maintained at a high level of more than 1 million tons since 1968. Squid began to decrease in the early 1970's. At that time, offshore fishing grounds of squid were developed in the Sea of Japan but poor catch became notable in the late 1970's including the offshore areas. Anchovy catch was kept fairly constant between about 300,000 and 400,000 tons since 1952. But decreasing trend became apparent since about 1973 and it is at a low level now.

After the collapse in the 1940's the sardine catch recovered to about 300,000 tons in around 1950 mostly in western Sea of Japan and in the East China Sea but this stock declined in the late 1950's. Around 1960 some increase of sardine catch was observed on the Pacific side of Honshu and it was hoped as a sign of overall recovery. But in 1964 unusually cold water prevailed around Japan and the Pacific stock of sardine was crushed. The catch of sardine declined to an extremely low level, recording only 9,000 tons in 1965. However, the 1972 year-class of the Pacific stock was unexpectedly large, and the catch began to increase markedly since 1973. This year-class laid abundant eggs and produced strong

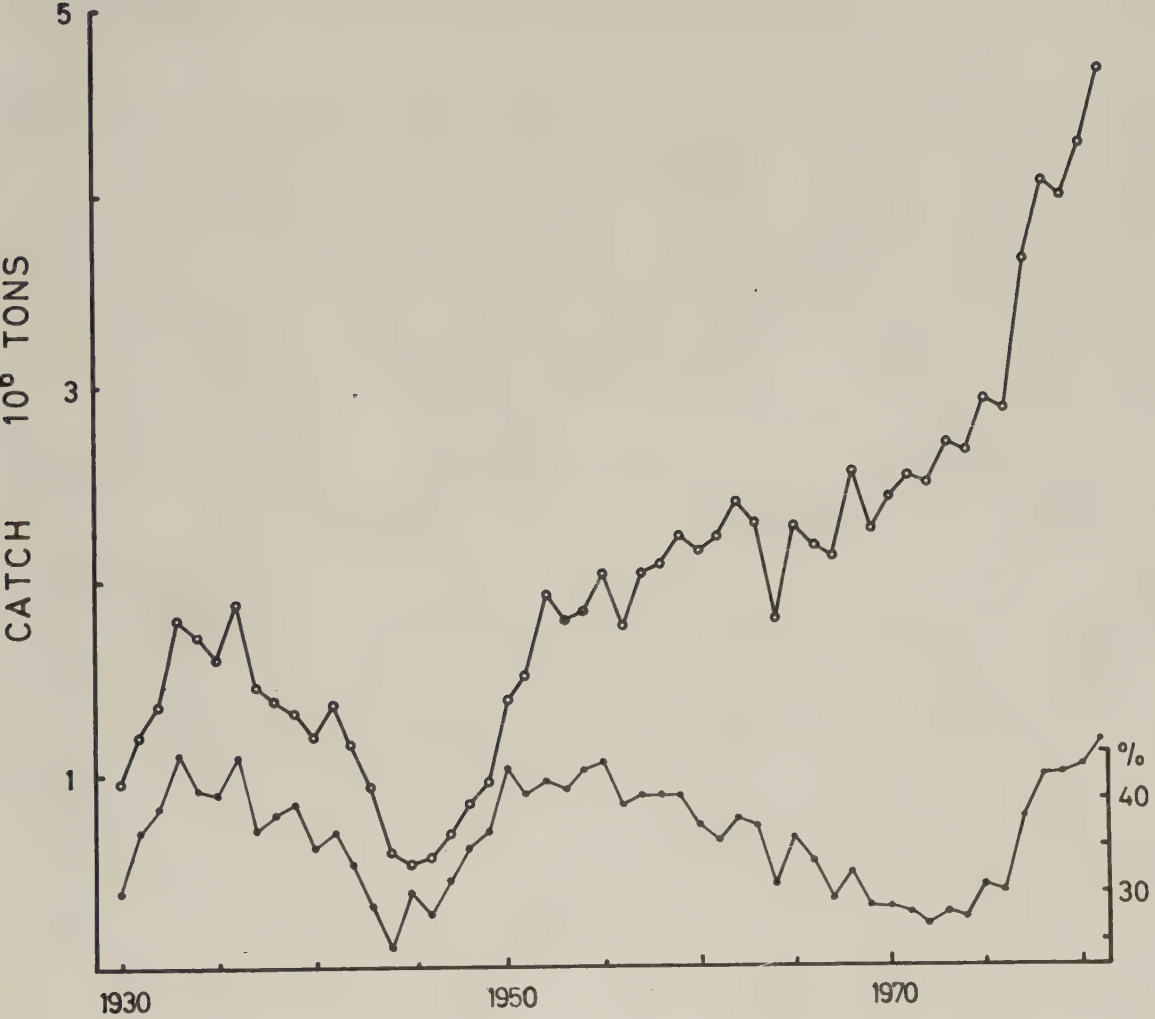

Fig. 1. Total of catches of warm-water plankton-feeding pelagic fishes and its percentage in the total landing of marine fisheries in Japan.

year-classes in succession. In 1976 the distribution was expanded as far north as off Hokkaido and the catch increased sharply. In parallel with the expansion of the Pacific stock, other stocks in the East China Sea and the Sea of Japan also increased considerably and the total catch of sardine reached 3 million tons which far exceeds the recorded maximum in the 1930's. Besides the Japanese catch, the Pacific stock is being caught by USSR fleets, yielding a few 10 thousand tons. Recently it is reported that sardine is occurring in the Maritime Province of Siberia.

Among changes of the catches of these species, it is noted that increases in mackerel catch took place concurrently with decline in catches of saury and jack mackerel, and again increase in sardine catch simultaneously with decline in catches of squid and anchovy. There are a number of arguments on the interrelation among these fish species (e.g. Mitani, 1970; Kawasaki, 1971). This subject will be dealt with in a later section.

Coefficients of variation (C.V.) of the catch of each species is given in Fig. 2. Squid and anchovy showed only a small variability with C.V. values of about 30% though their catches have declined recently. The values of C.V. are fairly large at about 50% for saury, jack mackerel and mackerel. Among these three, jack mackerel and mackerel showed considerable long term changes while saury showed both short term and long term variations. The value of C.V. for sardine is extremely high, i.e. 156%. Most of this large variability is due to long term changes and short term fluctuation is rather small. The ratio of the maximum catch in 1981 to the minimum in 1965 is as high as 340.

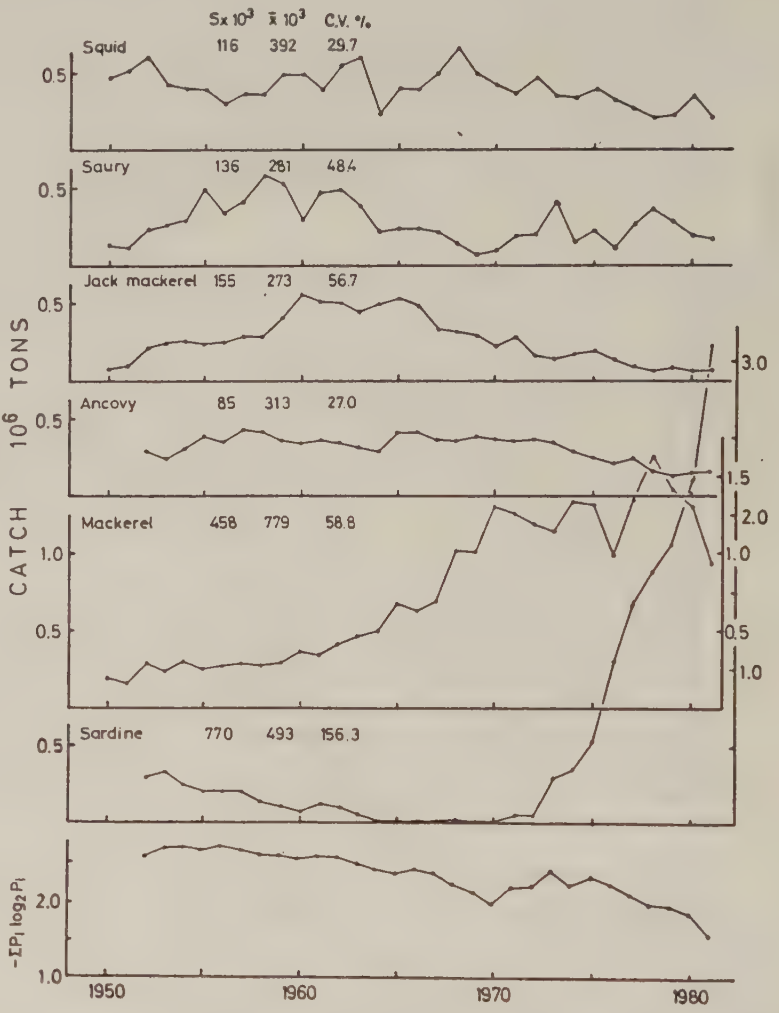

Fig. 2. Catches of warm-water plankton-feeding pelagic fishes in Japan and the diversity index of their compositions. $S_x$: standard deviation, $\bar{x}$: mean catch, C.V.: coefficient of variations.

Also shown in Fig. 2 is the diversity index of MacArthur (1955), that is $H = -\sum_i (Y_i/Y) \log_2(Y_i/Y)$, where $Y_i$ and Y are catch of i species and the total of them, respectively. In the 1950's when there was no particularly dominant species, the value of H was larger than 2.5. When sardine collapsed and mackerel formed a single dominant species around 1970, the value decreased below 2.0. The recovery of sardine catch temporarily made the diversity a little larger, but as the sardine catch becomes superlatively dominant the diversity is decreasing rapidly. The diversity is considered to be a measure of community stability and the total catch tends to be low when there is no particular dominant species and hence the diversity is high, and tends to be high when a particular species dominates and the diversity is low.

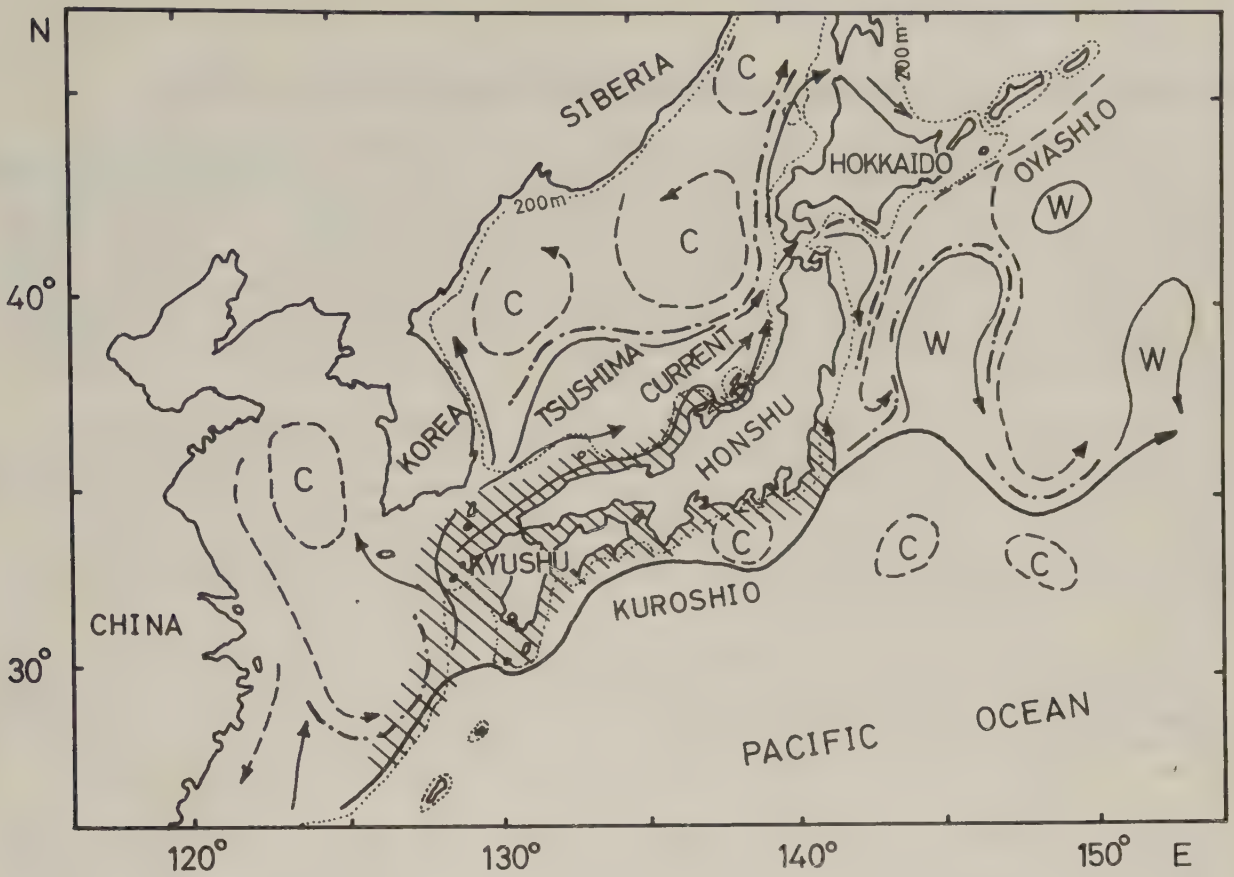
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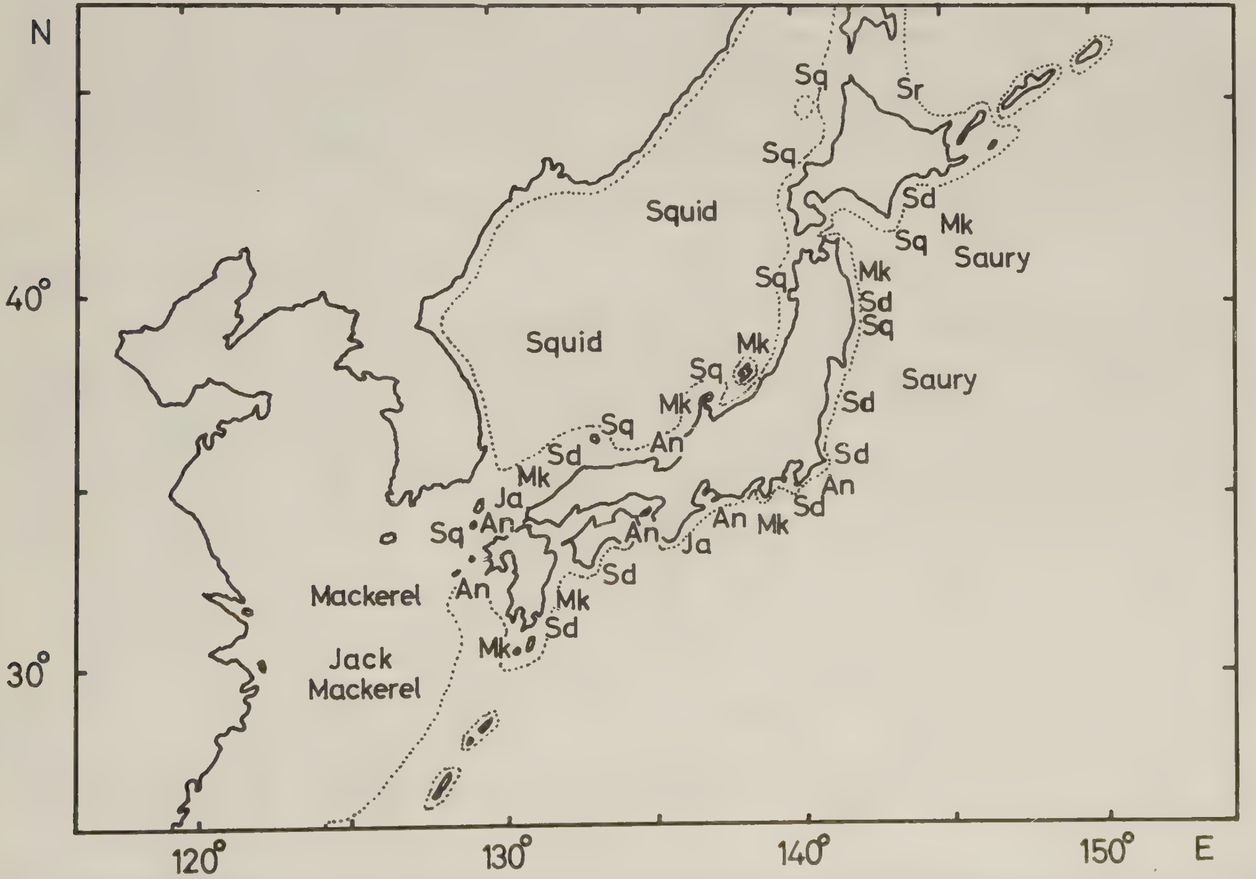
Fig. 3. Schema of current system around Japan. Real line: warm current, Broken line: cold current, W: warm water mass, C: cold water mass, Chain line: front, Shaded area: main spawning ground. (Data from Fisheries Agency).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Mackerel

Fig. 4. Fishing grounds of warm-water plankton-feeding pelagic fishes around Japan. Sd: sardine, An: anchovy, Ja: jack mackerel, Mk: mackerel, Sr: saury, Sq: squid. (Data from Fisheries Agency).

## Life history of warm-water plankton-feeding pelagic fishes and their fisheries

Warm-water neritic-pelagic fishes generally spawn in coastal waters inside the Kuroshio off southwestern Japan in winter and spring as shown in Fig. 3. Larval fish are transported eastward or northward by the Kuroshio and feed on abundant food and grow rapidly in the coastal waters of northern Japan or in frontal zone or mixing zone in offshore waters in summer and autumn. They winter in waters under the influence of the Kuroshio. The adult fish repeat the annual life cycle of northward feeding migration in summer and autumn, and southward spawning migration in winter and spring. Saury are distributed also in far offshore waters and spawn in outside waters of the Kuroshio or in areas of the Oyashio.

These pelagic species are caught in spawning grounds in winter and spring and in feeding grounds in summer and autumn (Fig. 4). Most of the catches of sardine, anchovy, jack mackerel and mackerel are obtained by purse seine fisheries. Saury are caught mostly by the stick held dip net fishery with light, and squid are taken by squid angling. Fishing grounds are generally developed in coastal waters but are extended to offshore areas as well for mackerel and jack mackerel in the East China Sea, for squid in the Sea of Japan, and for saury in the Pacific.

For each species it is considered that subpopulations are different between fish in the Kuroshio waters in the Pacific Ocean and those in Tsushima Current waters in the Sea of Japan. Furthermore, for sardine and mackerel *S. japonicus*, more than one subpopulation is recognized in each of the current systems. It is thought, however, that these subpopulations could be altered at times depending on such factors as the stock sizes.

The Pacific stocks of mackerel *S. japonicus* and sardine spawn in the Pacific Ocean off central Honshu and migrate as far north as Hokkaido in summer season. Each of them are the largest stock of the species and is supporting the majority of the total catch of each species. Purse seine boats are large and powerful and 400 tons of catch by one haul is not a rare example for sardine in summer and autumn season.

The Kuroshio often changes its route. Presence or absence of the cold water mass in the Pacific off central or western Japan greatly modifies the route of the Kuroshio. As shown in Fig. 5, 5 types, A, B, C, D and N, are observed. Each type has different effects on distribution and movement of fish shoals, and mortality in early life stages, and the change of types sometimes causes a turning point of stock size (Watanabe, 1982).

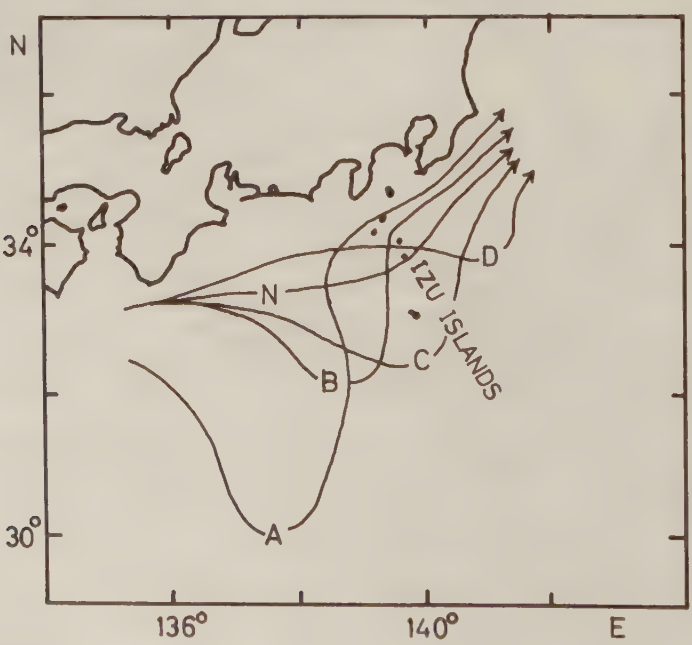

Fig. 5. Types of routes of the Kuroshio, south of Japan. (Data from Fisheries Agency).

## THE NORTHWEST PACIFIC STOCK OF SAURY

### Life history of the saury

The northwest Pacific Stock of saury has a wide spawning ground and a long spawning season. Shoals of the saury migrate southward in the Pacific Ocean off northern Japan in autumn season and start spawning while they are in waters north of the Kuroshio. The majority of the fish, however, cross the Kuroshio and continue to spawn in the vast area south of the Kuroshio till next spring. Adhesive eggs are laid on floating seaweeds. Egg diameter is relatively large ranging from 1.3 to 2.1 mm.

Larvae are drifted eastward or northward by sea currents in waters south or east of Japan and reach as far north as the central Kurile Islands in summer. They feed on abundant plankton in northern waters and grow rapidly. They start southward migrations in late August and are exploited intensively by the stick held dip net fishery. The fishing ground gradually shifts to south as season goes on, from water east of Hokkaido in September, and off northern Honshu in October to water off central Honshu in November and December, and then fishing ground disappears. The catch consists mainly of large sized fish (larger than about 28 cm in body length), medium sized fish (about 25-28 cm) and small sized fish (smaller than about 25 cm). Composition of these three size categories differs depending on year. Small sized fish tend to be abundant in years of poor catch. The age or growth problem is still to be clarified but it is considered that in fishing season in autumn, medium sized fish are just one-year-old and will mature in the season while small sized fish are younger than one year and will mature in the next season as large sized fish. Thus the large sized fish are less than 2-years-old. Sometimes extra large fish larger than 31 cm are caught but they are very small in number. Most saury are supposed to die after spawning.

The fish shoals are concentrated in the first branch (coastal branch) and second branch (offshore branch) of the Oyashio and fishing grounds are formed in these areas. Southward shifts of the fishing grounds coincide with the shift of the Oyashio front very well and it is apparently due to this that the southward movement of the fish is obstructed by the front (Matsumiya and Tanaka, 1976b). Southern limits of the fishing ground well correspond with the isothermal lines of surface water temperature of 16°C or 18°C (Tanaka, 1971a; b). When the front stays in the water off northern Japan for a long period of time, fish shoals do the same and good catches are expected. On the contrary, if the Oyashio current penetrates sharply into the mixing zone, fish disappear quickly from the fishing ground and the catch is generally poor.

### Population dynamics of the saury

The catches of saury in the Pacific off northern Japan in the period of 1954-1963 were high, ranging from 227,000-528,000 tons (average 389,000 tons). Since 1964 they dropped down to a level of 200,000 tons or less, and recorded very poor catches of 46,000 tons in 1969 and 73,000 tons in 1970. Kurita el al., (1973) analysed the dynamics of the northwest Pacific stock of saury and the effects of fishing on it. For the saury fishery, catch $y_{ij}$ and the numbers of fishing operations $x_{ij}$ are reported from sample boats for each 10-day-period. Relative index of the abundance of i 10-day-periods can be calculated using these data. The abundance index $P_i$ is usually calculated by the formula

$$P_i = \sum_{j=1}^{A_i} y_{ij}/x_{ij} \qquad (1)$$

However, a simpler formula

$$P_i = A_i \sum_{j=1}^{A_i} y_{ij} / \sum_{j=1}^{A_i} x_{ij} \qquad (2)$$

is applicable in case of the saury fishery. Effective fishing intensity of i 10-day-period $f_i$ is

$$f_i = Y_i/P_i \qquad (3)$$

An index of the abundance of available stock for each season may be given by the maximum $P_i$ in the season ($P_{max}$).

The catch and index of the abundance are shown in Fig. 6. The trend of the index is different from that of the catch. The catch fluctuated considerably in 1954-1963 period and dropped down since 1964, while $P_{max}$ showed much smaller fluctuation and did not show any decreasing trend until 1967. The distribution and movement of the saury are greatly affected by oceanographical conditions of the year and hence the catch is quite variable. If, for instance, fish are concentrated in a small area and stay there for a long time catch per unit effort would become high and a good catch would be obtained. Contrarily, if fish are distributed dispersedly or move quickly to the south and leave the fishing round, a bad catch would be expected. $P_{max}$ suggests that the abundance of available stock was fairly constant though the catch fluctuated considerably.

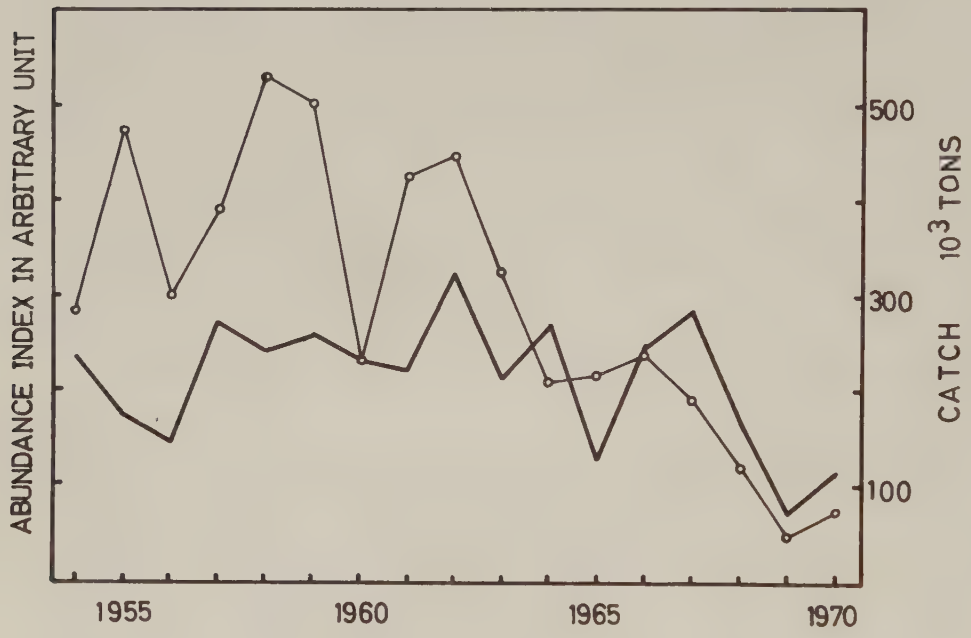

Fig. 6. Relative abundance index (thick line) and the catch (thin line) of saury in the northwest Pacific Ocean off northern Japan. (Kurita *et al.*, 1973)

A relative index of fishing intensity, that is the ratio of the total catch to the index of abundance ($Y_i/P_{max}$), is given in Fig. 7. The ratio indicates a relative value of the rate of exploitation. In this figure, the number of boats of the saury fishery is also presented. The relative index showed a considerable fluctuation according to the fluctuation of the catch, but still it indicated a clear decreasing trend. This trend well agreed with the trend in the number of the boats. It can be said that poor catch after 1964 occurred while fishing intensity has been reduced considerably.

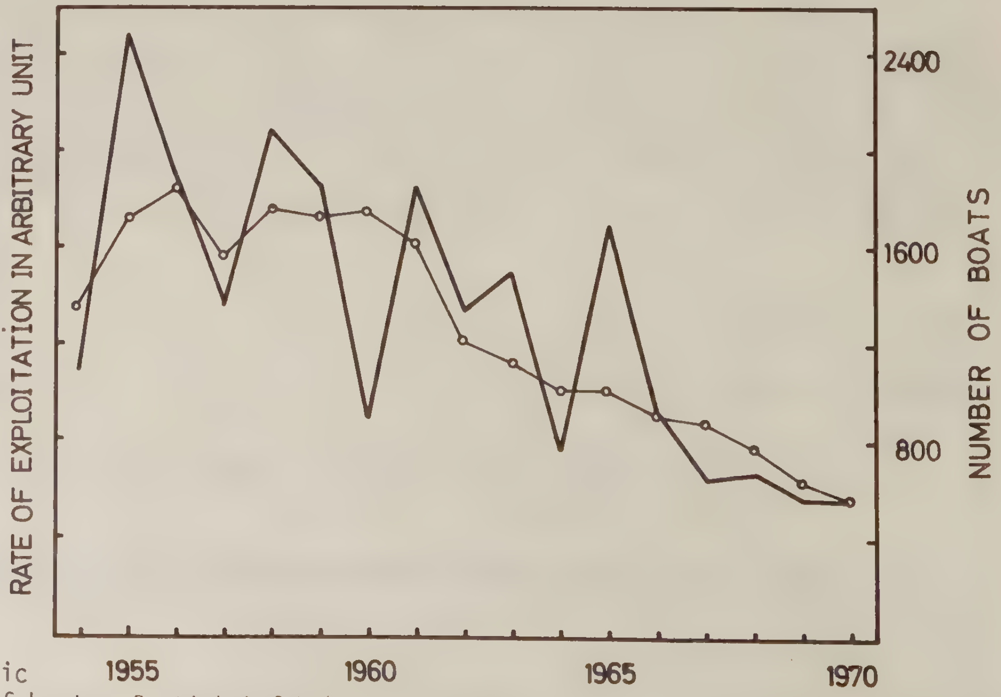

Fig. 7. Relative index of the rate of exploitation (thick line) of saury in the northwest Pacific Ocean and the number of boats of stick held dip net fishery (thin line). (Kurita *et al.*, 1973).

Seasonal change of $P_i$ within a season is generally that at the beginning of fishing season in August immigration of fish into fishing ground is not completed yet and the value of $P_i$ is low. It increases rapidly and reaches a peak usually in September and then turns to decrease gradually toward the end of the season in November or December. The rate of decrease after hitting the peak is different year by year and in some years a high level of $P_i$ continues for a fairly long period but in some other years $P_i$ decreases quickly. Trends in 1961 and 1962 when more than 400,000 tons of catches were obtained are compared with those in 1966 and 1967 when the catches were about 200,000 tons in Fig. 8 (Tanaka, 1971a; b). Between these two groups of years, there was almost no difference of $P_{max}$. However, decreasing rate was much different after mid October and caused a large difference in the catch.

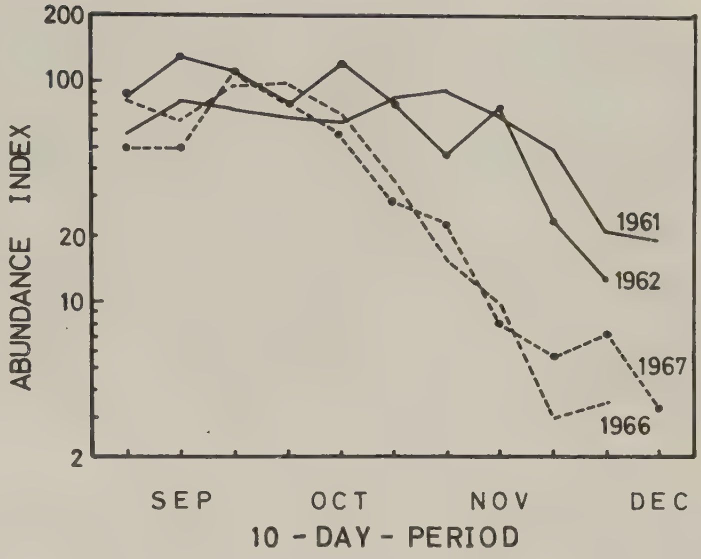

Fig. 8. Seasonal change of the available stock abundance of saury in the northwest Pacific Ocean. (Tanaka, 1971b).

Isothermal lines of the surface water temperature in mid October are shown in Fig. 9 taking 1962 and 1966 for examples. In 1962, isothermal lines ran in an east-west direction and prevented southward migration of the fish and hence the fish stayed long in the fishing ground. On the other hand in 1966, the Oyashio projected to the south and the fish disappeared quickly from the fishing ground.

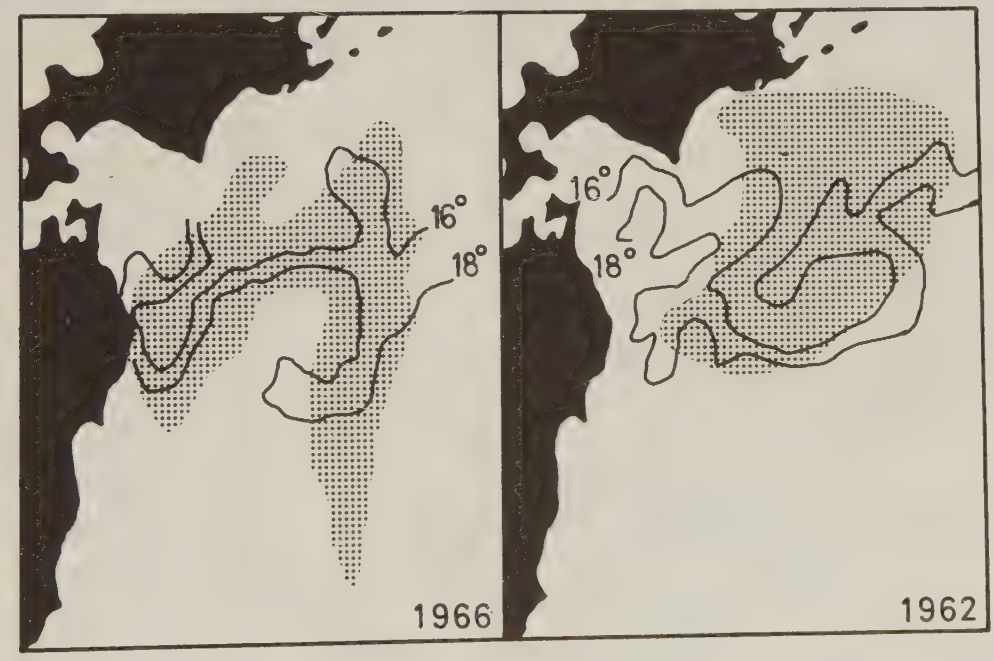

Fig. 9. Isotherms of surface water temperature and fishing ground of saury in mid 10 days of October. (Tanaka, 1971b).

Matsumiya and Tanaka (1976a) analysed length frequency data together with the catch and effort data and estimated annual rate of exploitation and the abundance of stock for the size categories of large and medium fish. The escapement post fishing season number was calculated and compared with the abundances of stock or recruitment. Matsumiya and Tanaka (1978) drew the reproduction curves separately for the large sized fish and medium sized fish assuming a two year lag from spawning to recruitment. After this paper was published, some doubt was thrown on the ageing of saury.

Here only the large sized fish is considered because age of them is assumed to be two-years-old. A stock and recruitment relation is presented in Fig. 10. Assuming two years as the maturation age, two independent cycles, an even-year-cylce and an odd-year-cycle, are defined like for pink salmon. Before 1960, failure in reproduction in the 1966 year-class caused a serious decline of the cycle. The odd-year-cycle also failed in reproduction in 1963 and again in 1967 and dropped down to an extremely low level. During these years no signs of a shortage of parent fish could be detected.

Because of its peculiar life history the saury is fished intensively in a short time period immediately before spawning, and effects of fishing do not appear as growth over-fishing but appear in reproduction through insufficient number of spawning fish. In the case of the northwest Pacific stock of saury, there is no evidence that the spawning stock was depleted by fishing. Furthermore, the poor catch happened after the intensity of fishing decreased substantially. Analysis of the stock and recruitment relation indicated that the decline of the stock was brought about by failure of reproduction. In 1971, the spawning stock was very small. Nevertheless this year-class produced in 1973 the largest catch since 1963. In summery, the saury catch is influenced: in short term by distribution and movement of fish affected by oceanographical conditions of the year and; in long term, by the stock level determined by success or failure of sequential reproduction.

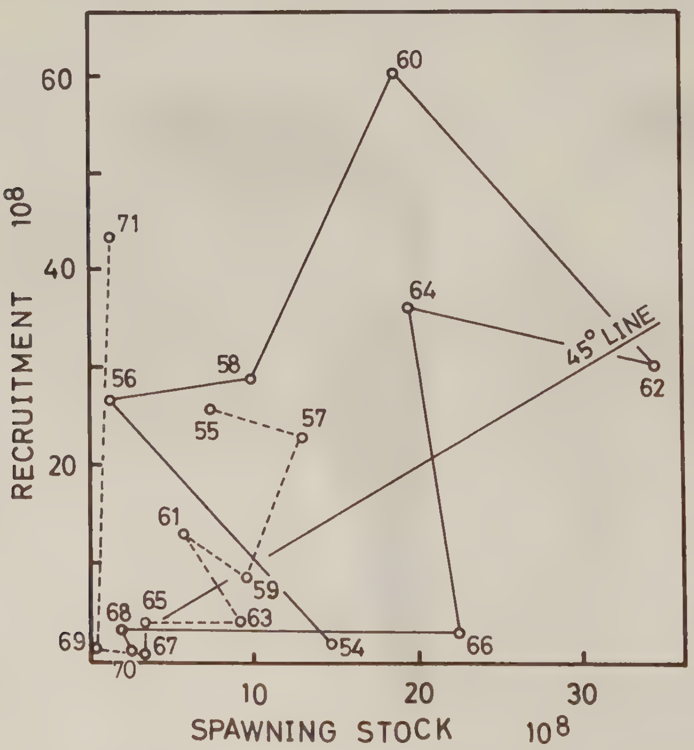

Fig. 10. Stock and recruitment relation of the large sized saury in the northwest Pacific Ocean. Numerals: year-classes. (Matsumiya and Tanaka, 1978).

## SOME EXAMPLES OF STOCK AND RECRUITMENT RELATION

### Hokkaido herring

The Hokkaido herring, like as other stocks of herring, showed remarkable year-class fluctuations. The catch was supported by dominant year-classes which appeared once every few years. Fishing was conducted by set nets and gill nets in spring for adult fish which concentrated in the coastal area for spawning. The maximum catch of 970,000 tons occurred in 1897, but a decline of catches started in the early 20th century from southern parts of the spawning grounds, and extended northward. In the 1930's frequency of occurrence and also the strength of dominant year-classes decreased markedly. A sign of a serious decline of the catches appeared in late 1930's. Suddenly in 1939 a large year-class came up. This year-class provided temporary good catches around 1945 and dominated the catch for 20 years. Disappearance of this year-class ended the fisheries of the Hokkaido herring.

Age composition data on the catches were collected for a long time. Only the number of gear is available as fishing effort data, but main gear was set net and fishing intensity is considered not to vary considerably. Thus the number in the catch by age is assumed to represent the survival process in the stock. Fish first appear in the catch as 3-year-olds, reach a peak in number at about age 5, and then turn to decrease in geometrical fashion with constant survival rate peculiar to each year-class. Reasons for difference in survival rate between year-classes are not known. The above mentioned 1939 year-class had unusually large value of survival rate at 0.73.

Stock and recruitment relations of the Hokkaido herring have been analysed (Tanaka, 1960). As the survival rate is not the same among year-classes, year-class strength is represented by the catch at age 5 when recruitment is completed. Fecundity is roughly proportional to the body weight of fish and hence total catch in weight is taken as an index of spawning. The result is presented in Fig. 11. It is rather difficult to find any relations as the points scatter very broadly. Nevertheless it is clear that up to the 1920's abundance of spawning was large and recruitment was also large on the average though it showed considerable variations. In the 1930's recruitment was kept very low and then the abundance of spawning began to decrease. The abundance of spawning decreased to low levels by 1939, but the large year-class appeared and the abundance of spawning was restored considerably in 1940's. Yet, no dominant year-class appeared again. Occurrence frequency of dominant year-classes is quite different between adult catch levels of larger than and smaller than 400,000 tons. If this trend was a real one inherent to biology of the herring, then it could be said that the Hokkaido herring stock collapsed by insufficient spawning due to overfishing.

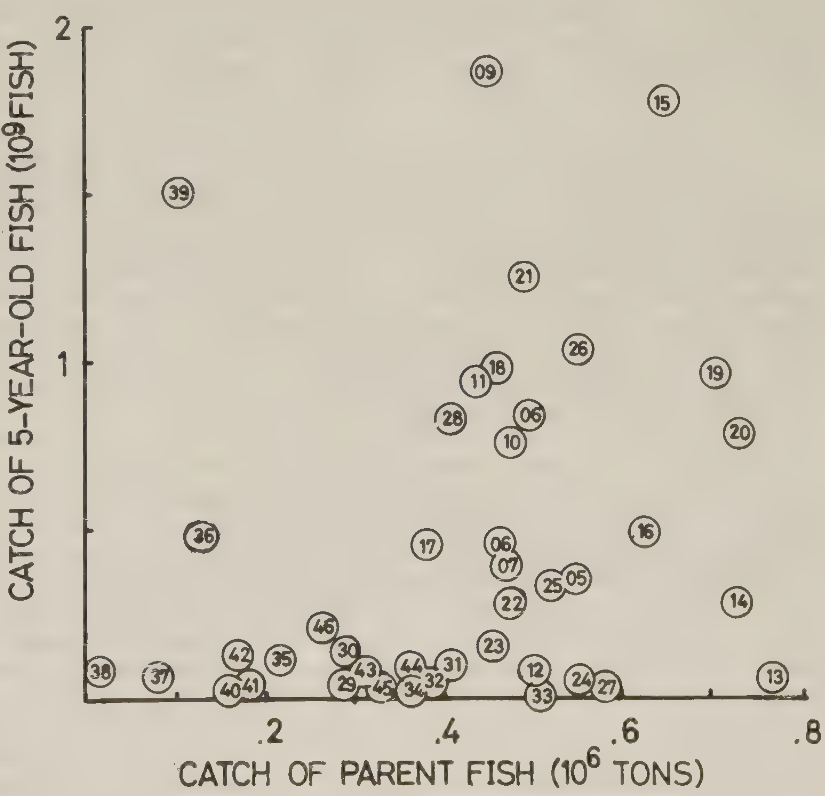

Fig. 11. Stock and recruitment relation of the Hokkaido herring. Numerals: year-classes. (Tanaka, 1960).

However, if the reproduction curve inherent to the stock had a shape usually observed, and that seems to be more reasonable, reason of the collapse was not deficiency in the spawning but a high mortality of fish before recruitment caused by some natural factors. The factor of high water temperature has been suggested (Hatanaka, 1949) but the factors are still not well understood.

## Pacific stock of mackerel

The Pacific stock of mackerel (*S. japonicus*) inhabit the coastal waters inside of the Kuroshio and spawn in water around the Izu Islands in the Pacific off central Honshu. Spawned eggs and larvae are transported by the Kuroshio and extend their distribution eastward and northward. Young fish come back and congregate in waters off central Honshu and winter there. One-year-old fish extend their distribution as far north as northern Honshu in summer and come back again to water adjacent to central Honshu in winter. In third year they join the adult fish stock as two-year-old fish, and migrate as far north as Hokkaido and southern Kurile and feed there in summer. When autumn comes, they move to the waters off northern Honshu, and begin to migrate southward along the coast and to return to the wintering area. They spawn for the first time at age 3 around the Izu Islands. The fish in feeding season are caught by the purse-seine fishery off Hokkaido and northern Honshu in summer and autumn season. In wintering and spawning seasons they are caught by the angling and scoop nets in waters off central Honshu and the Izu Islands.

The abundance of spawning is estimated every year since 1951 (Watanabe, 1972; 1982). The abundance was less than $50\text{x}10^{12}$ until 1956 but started to increase since 1957 and in 1961-1968 it repeated large fluctuations around $500\text{x}10^{12}$ level. During 1969-1971, it dropped below $200\text{x}10^{12}$ temporarily but increased again since 1972 and reached to $1{,}000\text{x}10^{12}$ level in 1974-1976. After this time it declined sharply. Spawning level in 1982 was reported to be very poor.

The age composition of the spawning stock was estimated every year and Watanabe allotted the abundance of spawning to each year-class and calculated the total abundance of eggs spawned by each year-class throughout its life. Comparison of spawnings by year-classes with the spawnings of the year of birth gives a stock and recruitment relation. The result is shown in Fig. 12. Points scattered near the origin in 1951-1953, started to move upward due to good reproductions continued from 1954 to 1957. Up to 1963, points moved toward the right forming a Ricker type curve, but the reproduction turned poor in 1964 and the stock showed a temporary fall. It started to increase again since 1969 and produced another Ricker type curve at a higher level. These two reproduction curves suggest excessive spawnings in 1964 and 1974.

The stock repeated large long term variations, with a peak in the mid 1960's originating from good reproduction in 1956 and 1957 year-classes, a decline around 1970 caused by a poor reproduction from 1964 to 1968. Another peak in the mid 1970's was brought about by a high reproduction since 1969. The catch was maintained at levels of one million tons or higher from 1968 to 1980. In 1978, the maximum of 1.3 million tons was recorded. The catch in 1980 was 1.0 million tons but it dropped drastically in 1981 down to only 420,000 tons. Fishing in 1982 was again poor. Although there is some possibility of overfishing and shortage of spawning around 1978 to explain the latest decline, long-term variations before these recent years indicated that the primary cause of the stock variation was the success or failure of reproduction and the meandering of the Kuroshio. Reproduction of year-classes from 1958 to 1962 and from 1970 to 1974 fit well with Ricker type curves, but it is noted that the levels of the curves are different between these two periods.

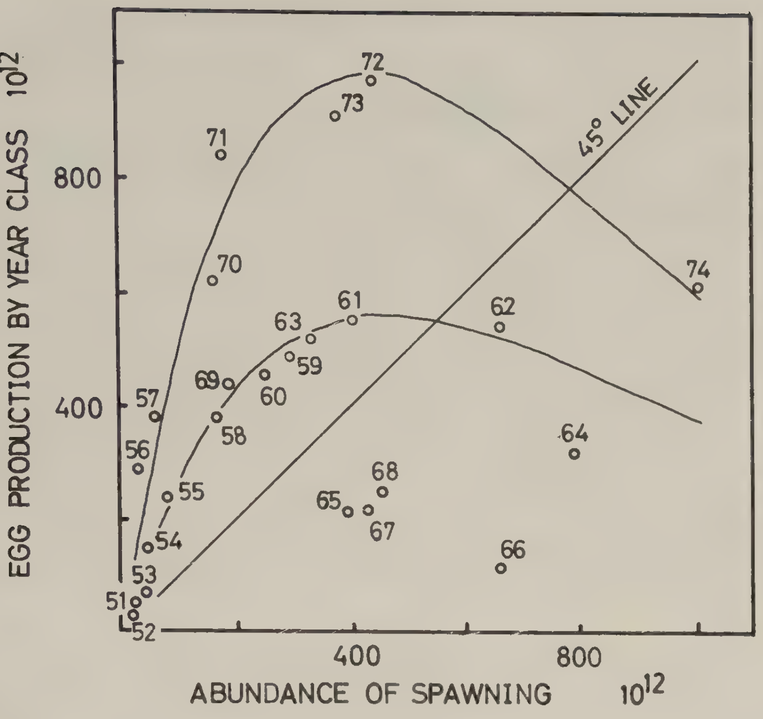

Fig. 12. Stock and recruitment relation of the Hokkaido herring. Numerals: year-classes. (Tanaka, 1960).

## Causes of collapse of sardine in the 1940's

A peak of catch in the 1930's seen in Fig. 1 was due to a good catch of sardine, and more than 80% of the total catch shown in the figure was accounted for by sardine. The catch of sardine hit a peak of 1,586,000 tons in 1936 and then turned to decline sharply (Kurita and Tanaka, 1956). Various explanations were presented for this decline. Nakai (1949) explained that at that time a large cold water mass appeared south of Honshu and the route of the Kuroshio was type A (see Fig. 5), and hence sardine larvae transported by the Kuroshio from the main spawning ground south of Kyushu in those years drifted away to far offshore waters and died from starvation, causing extinction of recruitment. Nakai's explanation was accepted to be most plausible. In waters off California, the sardine stock collapsed almost simultaneously with the Japanese sardine and it has been found that extinction of recruitment was the cause of the collapse (anon., 1953).

Kurita (1957) compared annual natural increase or production with the stock size assuming various levels of rate of exploitation and found that the relation was not like a parabola of the logistic curve but the natural increases in 1941-1943 were extremely low against the stock sizes of the years. He concluded from this analysis that recruitments of 1938-1941 year-classes were very poor due to some natural causes. He did not specify any natural factors but coincidence of timing of recruitment failure may endorse the Nakai's hypothesis.

Assuming a logistic type model for the sardine stock, and giving various values of the parameters of the logistic curve, r and K, trajectories of stock abundance from 1915 to 1950 are calculated applying the actual catch records. When r is large and K is small (e.g. $r = 0.68$, $K = 10^7$ tons) the stock declines once due to overfishing but it returns, increasing rapidly after 1942 due to reduced catches and cannot simulate the actual situation in which stock level was kept very low for a long time. If r is small but K is large (e.g. $r = 0.04$, $K = 30 \times 10^6$ tons), stock size is reduced considerably by fishing and stays at a low level similarly to the actual situation. But here r value is unreasonably small. This analysis leads to a conclusion that unless parameter values change, it is not likely that the sardine stock was reduced by overfishing and kept at a low level under a pressure of fishing. Even if overfishing was a real one, it is considered to be true that the productivity of the sardine stock was reduced drastically in the 1940's due to some causes other than overfishing.

## SOME DISCUSSION ON INTERACTION BETWEEN SPECIES

### Alternation of dominancy between saury and mackerel

As mentioned previously the catches of individual species of the warm-water plankton-feeding pelagic fishes in waters adjacent to Japan showed large fluctuations while the total catches have been fairly stable. There, alternations of dominant species were observed. As seen in Fig. 2, saury catch decreased while mackerel catch increased rapidly. Both the Pacific stocks of saury and mackerel feed in the frontal zone where the Oyashio and Kuroshio meet and spawn in waters under the influence of the Kuroshio. Both of them feed mainly on zooplankton. Hence the saury and mackerel are undoubtedly in competition. Mitani (1970) speculated on the alternation of the dominant species that i) the saury stock was depleted by overfishing, ii) the mackerel stock was in an upward trend at that time, and hence iii) the mackerel stock obtained advantages over the saury stock in competition for food and this resulted in the alternation of dominant species from saury to mackerel. This speculation is questionable because firstly there is no evidence of overfishing of the saury and secondly there is no explanation why the mackerel was in an upward trend. Further, any change caused by simple competitive interactions is reversible and so when fishing intensity of the saury was reduced the situation would likely have returned to the former state and dominancy of mackerel could not be maintained.

Kawasaki (1971) criticised Mitani's argument and stated that the alternation of species was caused by a change of the oceanographical environment. He denied possibility of overfishing by a reason that predation on plankton feeders by skipjack, tuna, porpoise and other predacious animals in the mixing zone is estimated to be much larger than the catch. Special features of oceanographical conditions in the Pacific off northern Japan at the time when the alternation occurred were that the Kuroshio shifted south and the Oyashio retreated north enlarging the mixing zone between these two currents. The mackerel mostly inhabit the Kuroshio and feed in the mixing zone. On the other hand, saury are mainly distributed north of the Oyashio and the retreat of the Oyashio pushed them further offshore and they could not use abundant plankton in the coastal waters. Kawasaki concluded that this situation caused the change of position from the the saury to mackerel. Among three species, (sardine, mackerel and saury) sardine is distributed in most offshore waters. Although it may be possible that some types of oceanographical conditions are favourable to coastal species and unfavourable to offshore species, it seems implausible that the same conditions last for more than 10 years. The problem of alternation of species should be discussed from two aspects; one is a trigger factor such as change of oceanographical conditions or effect of fishing, which destroys a stable state and causes alternation of species, and the other is a mechanism such as interaction between species, which stabilizes the new situation after change.

### Nonlinear interactions between species

Shirakihara and Tanaka (1978) confirmed Vandermeer's (1973) suggestion that nonlinear interaction between two species could produce alternations of dominant species. Generally, two species interaction can be expressed in a form of simultaneous differential equations:

$$\frac{dN_1}{dt} = G_1(N_1,N_2)$$

$$\frac{dN_2}{dt} = G_2(N_1,N_2) \qquad (4)$$

where $N_i$ is the stock size of i species, $G_i$ is a function of $N_1$ and $N_2$. The condition for equilibrium of $N_1$ or $N_2$ is:

$$G_1(N_1,N_2) = 0 \quad \text{or} \quad G_2(N_1,N_2) = 0 \qquad (5)$$

Taking $N_1$ on the abscissa and $N_2$ on the ordinate, these equations present curves which are called isoclines. Intersections of two curves are equilibrium points of the system. In case of the linear interaction, isoclines are straight lines and there is only one intersection. In ordinary circumstances this point is a stable equilibrium. When the equilibrium is broken by some disturbance, stocks always respond to restore equilibrium at the same point. Changes are reversible (Larkin, 1963). Under nonlinear interactions, however, isoclines form curved lines and may have more than one intersection. Therefore, it is possible a system has two stable equilibrium points. In such a system, there is a possibility of irreversible change that stocks at one equilibrium point are disturbed and pushed out of the point and drawn to the other equilibrium point. If original equilibrium point corresponds to point A in Fig. 13 where species I is dominant and new equilibrium point to point B where species II is dominant, then such irreversible change means an alternation of dominant species.

There is a possibility that nonlinear interactions really exist between the sardine and mackerel stocks. The mackerel prey upon the sardine. Therefore, a large stock of the sardine may be profitable for the mackerel. However, once the sardine stock grow up to such a high level as in recent years, the sardine would become a strong competitor occupying a part of the mackerel's habitat and exercizing unfavourable influences over the mackerel. Isoclines for the mackerel could have a form like curve I in Fig. 13. For the sardine, the mackerel are predators and also competitors on one hand but they prey upon anchovy and jack mackerel which are competitors of the sardine on the other. A small mackerel stock may allow anchovy and jack mackerel stocks to grow larger and may cause a low growth of the sardine stock. Hence the isocline for the sardine could be a curved line as shown by curve II in Fig. 13. This argument is nothing more than speculation with an over simplified model but still suggests an importance of studies from such a view point.

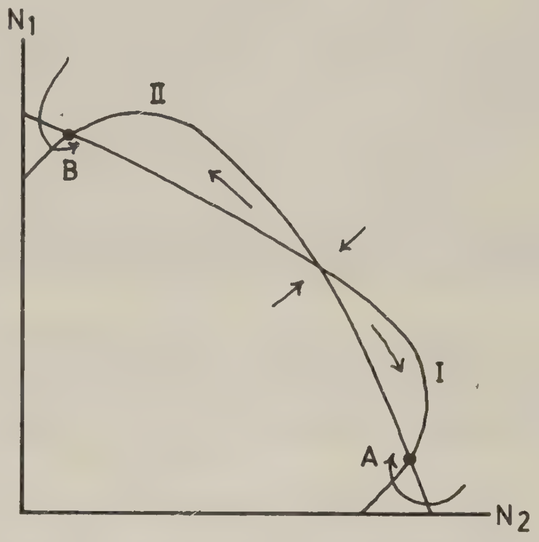

Fig. 13. Isoclines of two interrelated species with nonlinear interactions. Arrows indicate directions of movement.

## MANAGEMENT OF NERITIC-PELAGIC FISHES

It has been made clear from above discussions that neritic-pelagic fish stocks are very variable depending on natural environmental changes. Particularly, successes or failures of recruitment determines variation of the entire stock. There is almost no evidence that fishing is playing an important role in this large variability. Cessation of recruitment occurs even when spawning is fairly abundant. At the same time, there are quite a few examples of building up of stocks triggered by a relatively strong year-class produced from a very small egg production. This does not mean however, that fishing has no effect on fish stock at all. The effect of fishing must be measured in relation to the productivity of stock. High productivity can keep stock growing under an intensive fishing. On the contrary, even a weak fishing may accelerate collapse of stock under a low productivity due to unfavourable natural conditions.

In management of pelagic fish stocks, high variability of productivity depending on changes in environment should be kept in mind. It could not be possible even by complete closure of fishing in the 1940's to maintain the sardine stock at the high level of the 1930's. Under such a situation, fishing which is compatible with low productivity of stocks should be adopted. The fishery should maintain resilience under unfavourable productivity, to build up quickly when the environment allows more intense fishing.

It is certainly not easy to expand or reduce a fishery according to variation of productivity because a fishery is an economical activity. However, the fact observed in Japanese fisheries should be noted. That is, variability in the total catch of warm-water plankton-feeding pelagic fishes is much smaller than that in each species. Productivity of the sea must be fairly constant, not changing like catches of individual species. In order to maintain a stability of a fishery, the entire community of neritic-pelagic fishes should be exploited as a whole. Fortunately, most of neritic-pelagic fishes are caught by the same type of fishing gear. Japanese purse seine boats select freely their target fish which is most profitable to them among sardine, anchovy, jack mackerel and mackerel. The fishery can be continued regardless of large variabilities of individual stocks if it is exploiting the community of neritic-pelagic fishes as a whole.

One of the serious problems in doing so is the differences in prices and demands among various species of fishes. In Japan each of the above-mentioned species has a basic demand as human food. When sufficient amounts of fish cannot be supplied for human food, due to poor catch, then the price goes up and income of fishermen is kept relatively high in spite of a small catch. When the catch becomes very large and far exceeds the demand as human food, the price drops down and a large demand is created as material for reduction and feed. By such a mechanism, Japanese fisheries for neritic-pelagic fishes can survive under very unstable conditions of resources. It seems to be necessary to develop such a flexibility in demand and organization for circulation.

The proper management of neritic-pelagic fishes which show large fluctuations depends much upon the prediction of productivity. To this end, predictions of recruitment as well as of abundance of available stock are needed. Such research as stock and recruitment relations, relations between the distribution and movement of fish and oceanographical conditions and the abundance of prerecruited fish are required.

Notwithstanding extensive researches, it is very difficult to predict precisely the productivity of stocks. Therefore, except long living species such as herring, a regulation by catch limit system seems not to be effective. Regulation of fishing effort by, say limiting the number of boats, may be effective.

Tanaka (in press) calculated yield per recruit and egg production per recruit for various values of natural mortality M, life span T and K of Bertalanffy's growth curve. He found that provided that only adult fish are exploited, effect of fishing would not be serious for short-life species such as anchovy and relatively long-life but large K value species such as sardine. Assuming the age of first capture is at the age of first maturation, yield per recruit increases with the value of fishing coefficient of F. Egg production per recruit at F = 1.0 (roughly 40 to 50% in the rate of exploitation) is reduced to about 1/3 for sardine and 1/2 for anchovy relative to that at F = 0. A decrease in egg production by this extent seems not likely to reduce recruitment considerably. This situation is altered substantially if immature fish are exploited. With F = 1.0, the egg production would not be reduced less than 1/3 for anchovy, but may be reduced less than 1/10 for sardine.

Adults and immatures of pelagic fish often form different shoals and selective fishing only for adult fish is relatively easy. It is desirable to try to reduce the catch of immature fish as much as practicable. In any case, reduction of egg production to low levels should be avoided. Optimum egg production may vary depending on the environmental conditions and hence efforts to keep egg production at a fixed level are not practical.

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*NORTH WEST PACIFIC AND SEA OF JAPAN - PACIFICO NORDOCCIDENTAL Y MAR DEL JAPON*

# SOME EXPLANATION FOR CHANGES IN ABUNDANCES OF MAJOR NERITIC-PELAGIC STOCKS IN THE NORTHWESTERN PACIFIC OCEAN

by

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## Resumen

Hay once productos que se extraen de los recursos neríticos-pelágicos que son importantes para la pesquería Japonesa. Estos son sardina, anchoveta, postlarvas de estas dos especies, arenque redondo, arenque del Pacífico, caballa, jurel, sábalo, saury del Pacífico, calamar común de aleta y calamares miscellaneos. La captura total se ha mantenido alrededor de dos millones de toneladas de 1953 a 1970, aumentó desde entonces, y ha pasado de 4 millones de toneladas por año entre 1977 y 1980. Los estados vecinos también han extendido sus actividades de pesca, pero entre 1970 y 1980 la flota Japonesa todavía producía entre el 74 y 80 por ciento de la captura total. Aun cuando todavía es posible explicar las fluctuaciones de los recursos pelágicos-neríticos en base a los datos Japoneses, se hace cada vez más necesario extender la cooperación internacional en el campo de biología pesquera, específicamente en el caso de arenques, sardina, caballa y saury. Las estadísticas Japonesas de 1953 a 1980 indican que de estos once productos, nueve de ellos asi como las poblaciones de peces relacionadas experimentaron aumentos o disminuciones más o menos notables durante los últimos 28 años. El arenque del Pacífico se ha mantenido en una disminución continua, mientras que las capturas de calamares miscellaneos muestran un incremento constante debido a la explotación de nuevos stocks.

Investigaciones anteriores revelan que hay algunos factores ambientales que han afectado seriamente la abundancia, distribución y otras características biológicas a las especies costeras. La caída y recuperación de la sardina está bastante bien documentada sobre la base de los datos tomados de la pesquería comercial y de los censos de huevos y larvas y las observaciones oceanográficas acumuladas a partir de los años 1930. Las capturas aumentaron en los años 1920s junto con una rápida expansión de las áreas de pesca, no solamente en las aguas alrededor de las Islas Japonesas pero también a lo largo de la costa oeste del Mar del Japón desde la Península de Corea hasta Sakhaline. La pesquería que se fue expandiéndo rápidamente dependió de la extensa migración de las subpoblaciones. El área principal de desove está localizada en el área de Satsunan, extremo sur de la Isla de Kyushu. Los huevos y larvas son arrastrados a lo largo de la costa del Pacífico de las Islas de Shikoku y Honshu por la corriente de Kuroshio. Los peces pasan el segundo y tercer año de sus vidas frente al noroeste de Honshu, donde las aguas de mezcla aseguran una alta productividad del plancton de forraje. Los adultos son principalmente capturados en el Mar del Japón y migran hacia el sur para el desove a fines del otoño e inicios del invierno. Los extensos serpenteos de la corriente de Kuroshio resultan en la acumulación de larvas de sardinas en las poco fértiles aguas mar afuera, y los stocks de larvas sufrieron una alta mortalidad a mediados de los años 1940. Desde entonces las áreas principales de distribución fueron cambiando de año en año y éstas se encontraron en el Mar Oriental de la China frente al este de Kyushu en 1951 a 1953, en el Mar de Japón cerca a la parte central de Honshu alrededor de 1955, y en las aguas del Pacífico a lo largo de la parte central de Honshu desde 1957. Los peces parecen haber ido incrementado gradualmente en los años 1960s en las aguas del Pacífico a pesar de la interrupción debida a una anomalía ambiental en 1963. La actividad del desove se ha extendido rápidamente desde 1972, y una significativa cantidad de huevos han sido encontrados en el área de Satsunan a partir de 1976, cuando las capturas sobrepasaron un millón de toneladas, tal como ocurrió en el próspero período anterior en los años 1930s.

Se han detectado cambios ecológicos similares en el arenque del Pacífico. La caballa común también ha mostrado cambios significativos en sus áreas de pesca y áreas de desove. Se nota que todas estas poblaciones están compuestas de tres o más grupos de edad.

Las capturas de saury del Pacífico han mostrado una amplia variación en años sucesivos. Pero no hay ninguna tendencia notable a largo tiempo en esta especie. Las áreas de pesca en esta especie varían, siempre en las aguas del Pacífico, de zonas costeras a zonas mar afuera debido a condiciones oceanográficas. Especies de vida corta como anchoveta y calamar, además del saury, muestran una significativa variación en el tamaño de sus stocks y también frecuentemente en las áreas de concentración que varían a corto plazo, lo que hace que los pronósticos previos al inicio de la estación de pesca sean muy útiles para estabilizar las operaciones de pesca. Sin embargo, la extensión geográfica de las áreas de desove y áreas de pesca parecen ser más estables en las especies de vida corta que en la sardina, herenque y otros peces de vida más larga.

Las especies neríticas-pelagícas parecen formar ecosistemas más o menos interelacionados como se sugiere por el hecho de que la captura total ha sido más o menos estable o ha mantenido un incremento más o menos constante a pesar de la notable variación de las especies individualmente, especialmente aquellas que tienen una gran biomasa. Además, estos recursos sorportan la mayor proporción de la producción de peces en el Océano Pacífico noroeste. Por lo tanto, cualquier regulación de las actividades de pesca tendientes a asistir la recuperación de especies reducidas por causas naturales debe evitar disturbar la producción de las otras especies que sustituyen a las especies problema en estas áreas. Es esencial que se seleccionen las áreas claves donde la población de una especie problema debe ser protegida de la presión de la pesca. Para que la ejecución de las regulaciones pesqueras sean practicables, es indispensable tener un amplio entendimiento o un amplio conocimiento de la ecología de las principales especies.

Las estadísticas de capturas y esfuerzo no siempre proveen información confiable sobre la abundancia de los stocks pelagícos debido a las diversas fuentes de variación en la accesibilidad y vulnerabilidad a las pesquerías. Al evaluar los stocks de sardina y caballa común solo se utilizan los censos de huevos en forma extensa. Sin embargo, los trabajos de campo y de laboratorio, requieren mucho tiempo, especialmente para especies con áreas de desove muy extensas. Las técnicas acústicas no están todavía lo suficientemente maduras como para permitir evaluaciones cuantitativas de los stocks de peces en el noroeste del Océano Pacífico. Se requiere un desarrollo tecnológico para proveer medios útiles que permitan introducir en breve tiempo medios más eficientes para medir los stocks pelagícos.

## INTRODUCTION

Variations of fish stocks assert considerable influence upon Japanese society in which the marine products have long been most dominating sources of animal protein. Uda (1952) and Nakai (1962) quoted historical documents which have suggested wide fluctuation in the stocks of sardine and other neritic-pelagic fishes that might have resulted in prosperity and destruction of villages in various parts of the country.

The remarkable decline of sardines in the 1940's was a very embarrassing event for the society which was suffering definitive shortage of the animal protein supply. In 1949 the Cooperative *Iwashi* Resources Investigation was initiated with the aim of clarifying causes of the drastic decline of sardine resources as the first nation-wide systematic investigation of fisheries resources in this country (Nakai et al., 1955). The decline of sardines drove the fishing fleet to catch substitute species such as anchovy, jack mackerel and common mackerels and the investigations were amended so as to cover all the major plankton feeders in 1955 (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan, Fisheries Agency 1961). At the present stage biologists have realized that the wide fluctuation in amount of stock of a species was often compensated by that of other species, and total catch of all the plankton feeders have stayed at fairly constant levels (Nagasaki 1973).

In and after 1960, USSR, Republic of Korea and other countries have expanded the fishing activities in the northwestern Pacific. The fishing exploitation encouraged related investigations. In 1963 the Cooperative Study of Kuroshio or CSK was initiated as a joint activity of UNESCO and FAO (Marr 1968). Japan and USSR organized joint consultations of the stocks of Pacific saury each year since 1968. The consultations expanded the topics recently, so as to cover common mackerels since 1976 and sardines since 1980 (Research Division of Fisheries Agency, Japan, 1980). The international cooperations have deepened the understanding of fisheries resources in relation to the fishing activity and oceanographic changes.

Briefed in this report are time series of catch statistics of eleven commodities important to the Japanese neritic-pelagic fisheries for 28 years from 1953 to 1980 compiled from the official statistics (Hayasi unpublished), together with international data since 1970 in the northwestern Pacific (FAO 1975, 1981). Changes of stocks due to environmental causes are included here from major papers explaining fluctuation in the amount of catch. Fishing-induced changes of stocks are described in a separate paper (Tanaka - this volume).

## CATCH STATISTICS OF MAJOR NERITIC-PELAGIC SPECIES

In 1955 the Japanese fishery biologists have listed eight important neritic-pelagic species or groups of species including sardine or *ma-iwashi* in Japanese language, *Sardinops melanosticta* (Temminck & Schlegel), round herring or *urume-iwashi*, *Etrumeus teres* DeKay, anchovy or *katakuchi-iwashi*, *Engraulis japonica* (Hottuyn), common mackerels of *ma-saba*, *Scomber japonicus* (Houttuyn), and *goma-saba*, *S. tapeinocephalus* Bleeker, jack mackerel or *ma-aji*, *Trachurus japonicus* (Temminck & Schlegel), scads or *muro-aji-rui*, *Decapterus* spp, common flying squid or *surume-ika*, *Todarodes pacificus* Steenstrup, and *shirasu* or mostly postlarvae of sardine or anchovy, together with some miscellaneous coastal fishes. The word "important" means that these eight commodities have appreciable biotic production or such potential. Even though recent changes of life styles resulted in shifts of preference for food stuffs including fishes, and the demand has abated for these species in the fresh fish market, they are still important as the raw materials for aquaculture, poultry, food industries, etc. Furthermore, these species represent major tertiary producers in the neritic-pelagic biota. Thus changes of these species populations determine not only the nation's nominal catch, but also the predacious species which comprise many high priced food items. Ecologically, three species should be added to the list, Pacific herring or *nishin*, *Clupea pallasi* Cuvier & Valenciennes, in the borealic waters, Pacific saury or *sanma*, *Cololabis saira* (Brevoort), that represents significant biomass in the mixing waters of the warm Kuroshio Current and the cold Oyrshio Current and the miscellaneous squids, of which a kind of flying squid called *aka-ika* in Japanese language, *Ommastrephes bartrani* (Lesuer), comprises the most significant portion.

Expansion of non-Japanese fishing activities resulted in the decline of the share of Japanese in the production of the eleven commodities from about 4/5 in 1970 to about 3/4 in 1980 (FAO 1975,1981). The Japanese share is especially low, 5 to 30 percent, for herring, which has been mostly taken by USSR and Chinese fisheries. Anchovies were reported mostly in Japan, over 77 percent in 1970 to 1973, but Korean catch gradually increased, lowering the Japanese share below 50 percent since 1978. Percentages of Japanese catch of other commodities appear to have been stable, 81 to 100 percent for sardine, 70 to 100 percent for round herring, 70 to 93 percent for mackerels, 90 to 99 percent for jack mackerel, 84 to 100 percent for scads, 57 to 83 percent for Pacific saury, 85 to 92 percent for common flying squid, and 65 to 87 percent for the miscellaneous squids. Thus, Japanese data still appear to represent the changes of most of the stocks under discussion.

Table 1 shows the amount of catch together with means and coefficients of variation of the eleven commodities based on the official statistics. The period of 28 years was chosen because the statistics survey system in this country was re-established in 1951, and the figures became reliable for most of the commodities since 1953. A longer series of statistics since 1926 indicates that the herring catch has been on the continuous decline and the years under discussion remain in the general decreasing period. The miscellaneous squid increased since 1964 due to recent exploitation of some flying squids in the north- and southwestern Pacific Ocean as substitutes to the common flying squid. However, the 28-year period covers rise and fall of the other species, and appears to represent enough duration of the usual fluctuations.

The figures given in Table 1 indicate significant variation exceeding 50 percent for sardine, mackerels, herring, jack mackerel and miscellaneous squids. The large variations of herring and miscellaneous squids must be responsible to the considerable change of stocks and fisheries. Pacific saury and scads follow these unstable species with the coefficient of variations of around 50 percent. The other species are more stable with coefficients of variation of 26 to 34 percent.

## EXPLANATION OF FLUCTUATIONS IN FOUR COMMODITIES

Systematic surveys have indicated possible environmental causes responsible for the wide fluctuation in the sardine population. The same factors might have had different effect upon ecologically related species so as to stabilize the amount of total catch of these species. Information was also made available for identifying non-fishing factors on the changes of herring, saury and flying squids. In the past, the environmental factors appeared to have played leading roles in determining the abundance and distribution of the neritic-pelagic populations in the northwestern Pacific Ocean.

### Sardine and related species

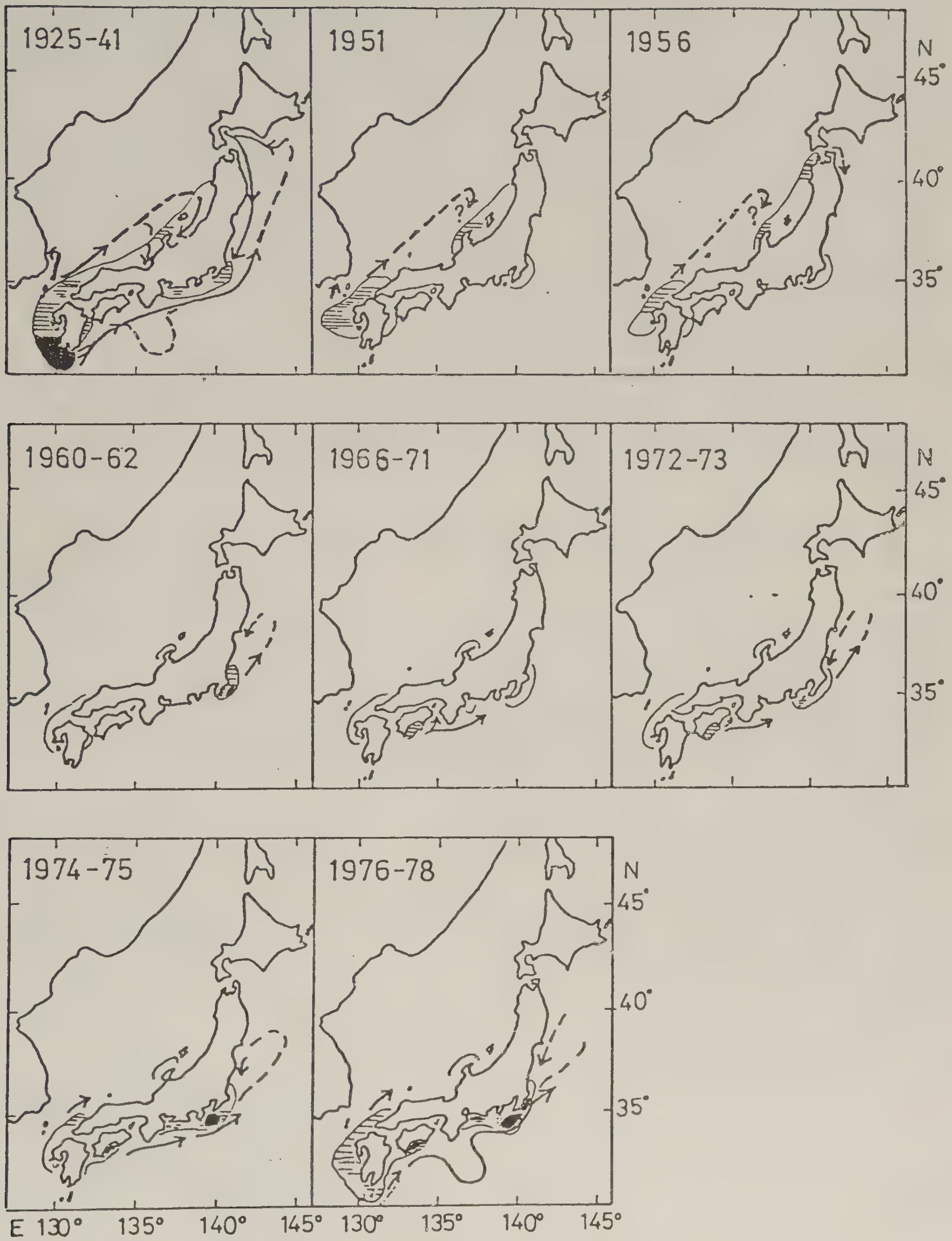
The sardine, besides Alaska pollock, *Theragra chalcogramma* (Pallas), represents the most prospering species in the North Pacific, having exceeded two million tons in annual catch. There are many fishes which are ecologically and commercially related to the sardine. A commodity called *iwashi* in Japanese language refers to either sardine or a group of round herring, and some other clupeids as well. The three species occur over almost the entire coastal waters around the Japanese Islands except northern Hokkaido and also the Ryukyu Islands. The same fishing gears catch all these three species, often concurrently. Furthermore, the most productive purse seine fishery for them also largely depends upon common and jack mackerels.

The wide variation in amount of catch of sardine was accompanied by extensive geographic shift of the fishing and spawning grounds. When the co-operative investigation was commenced in 1949, it was urgent to identify the major causes of decrease of sardine catch among three general possibilities, drop of availability due to change of migratory routes, or decline of stock size due to either overfishing or environmental causes. With the aim of clarifying the mechanisms underlying the drastic changes of sardine population, Nakai (1962) analysed the data taken in the years up to 1960. Later Kondo (1980) and Watanabe (1981) added information obtained in the following years of the recovery.

Table 1. Yields of major neritic-pelagic fishes in Japan, 1953-1980.

| | Herring | Sardine | Round-herring | Anchovy | Shirasu | Jack mackerel | Scads | Mackerels | Saury | Common flying squid | Other squids | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1953 | 275 175 | 343 623 | 52 503 | 243 476 | 20 433 | 239 115 | .. | 234 776 | 253 661 | 420 086 | 47 838 | 2 130 686 |
| 1954 | 132 251 | 245 640 | 47 988 | 304 031 | 22 717 | 250 073 | .. | 297 393 | 292 717 | 398 745 | 30 244 | 2 021 799 |
| 1955 | 46 837 | 211 342 | 66 363 | 391 522 | 28 237 | 238 372 | .. | 244 402 | 497 002 | 383 419 | 37 470 | 2 144 966 |
| 1956 | 35 557 | 206 302 | 59 947 | 346 706 | 28 616 | 246 416 | .. | 266 197 | 327 813 | 299 486 | 36 113 | 1 853 153 |
| 1957 | 47 265 | 212 238 | 52 815 | 430 211 | 21 150 | 281 568 | 31 065 | 275 329 | 421 530 | 364 365 | 39 251 | 2 176 787 |
| 1958 | 38 348 | 136 654 | 56 544 | 417 281 | 23 198 | 282 127 | 42 247 | 268 442 | 575 087 | 354 225 | 38 770 | 2 232 923 |
| 1959 | 16 925 | 119 581 | 47 067 | 356 232 | 28 602 | 409 616 | 22 640 | 294 543 | 522 566 | 480 667 | 38 329 | 2 336 768 |
| 1960 | 15 367 | 78 101 | 48 877 | 349 175 | 21 381 | 551 603 | 44 119 | 351 149 | 287 071 | 480 661 | 41 736 | 2 269 240 |
| 1961 | 23 595 | 127 049 | 26 724 | 366 934 | 24 006 | 510 732 | 31 400 | 337 785 | 473 792 | 383 993 | 40 194 | 2 346 204 |
| 1962 | 20 749 | 108 002 | 27 169 | 349 451 | 26 313 | 449 012 | 19 228 | 408 725 | 483 160 | 536 470 | 42 348 | 2 520 627 |
| 1963 | 14 597 | 55 861 | 28 908 | 320 609 | 18 696 | 441 175 | 21 691 | 464 886 | 384 548 | 590 647 | 41 231 | 2 382 849 |
| 1964 | 56 643 | 16 243 | 32 279 | 295 897 | 38 355 | 496 451 | 23 095 | 495 664 | 210 689 | 238 290 | 67 868 | 1 971 474 |
| 1965 | 50 169 | 9 215 | 29 073 | 405 906 | 32 824 | 526 885 | 33 602 | 668 574 | 231 377 | 396 902 | 82 071 | 2 466 598 |
| 1966 | 48 617 | 13 465 | 26 309 | 407 665 | 33 771 | 477 084 | 37 304 | 642 423 | 241 840 | 382 899 | 86 707 | 2 380 084 |
| 1967 | 63 672 | 16 801 | 24 023 | 365 240 | 34 976 | 327 878 | 95 474 | 687 474 | 220 087 | 477 012 | 104 100 | 2 416 737 |
| 1968 | 67 920 | 24 378 | 35 187 | 357 668 | 41 597 | 311 375 | 46 717 | 1 015 279 | 140 204 | 668 364 | 90 065 | 2 798 754 |
| 1969 | 85 240 | 20 561 | 29 156 | 376 801 | 32 378 | 282 817 | 57 771 | 1 011 406 | 63 288 | 478 160 | 95 173 | 2 532 751 |
| 1970 | 97 374 | 16 767 | 23 895 | 365 471 | 35 479 | 215 560 | 53 751 | 1 301 918 | 93 129 | 412 240 | 91 937 | 2 707 485 |
| 1971 | 100 483 | 57 429 | 47 126 | 350 692 | 40 657 | 270 870 | 44 600 | 1 253 892 | 190 288 | 364 349 | 102 756 | 2 823 142 |
| 1972 | 62 198 | 57 883 | 48 767 | 369 688 | 50 819 | 151 778 | 42 064 | 1 189 910 | 196 615 | 464 365 | 119 995 | 2 754 082 |
| 1973 | 82 658 | 296 864 | 40 422 | 335 425 | 58 251 | 128 054 | 54 666 | 1 134 503 | 406 445 | 346 672 | 116 228 | 3 000 188 |
| 1974 | 76 273 | 351 684 | 46 164 | 287 516 | 39 308 | 165 489 | 50 235 | 1 330 625 | 135 462 | 355 005 | 117 759 | 2 955 520 |
| 1975 | 66 617 | 526 047 | 43 936 | 245 164 | 47 052 | 185 669 | 49 647 | 1 318 210 | 221 573 | 378 344 | 137 066 | 3 219 325 |
| 1976 | 66 083 | 1 065 692 | 52 476 | 216 664 | 60 150 | 127 704 | 78 963 | 978 826 | 105 419 | 300 963 | 169 975 | 3 222 915 |
| 1977 | 19 873 | 1 419 826 | 44 829 | 244 933 | 42 005 | 87 457 | 98 344 | 1 355 309 | 253 465 | 264 287 | 227 963 | 4 058 291 |
| 1978 | 6 708 | 1 637 380 | 50 573 | 152 428 | 41 194 | 57 992 | 95 139 | 1 625 865 | 360 213 | 257,117 | 243 824 | 4 528 433 |
| 1979 | 6 819 | 1 817 034 | 49 461 | 134 577 | 55 313 | 82 515 | 101 368 | 1 414 183 | 277 960 | 212 841 | 301 853 | 4 453 924 |
| 1980 | 11 154 | 2 197 744 | 38 416 | 150 606 | 55 197 | 53 664 | 91 313 | 1 301 121 | 187 155 | 331 225 | 344 977 | 4 762 527 |
| MEAN | 58 399 | 406 765 | 42 034 | 319 213 | 35 810 | 282 109 | 52 768 | 791 100 | 287 648 | 393 636 | 104 780 | 2 766 724 |
| S.D. | 53 104 | 614 922 | 11 887 | 81 864 | 12 242 | 153 785 | 26 451 | 464 458 | 138 714 | 103 828 | 83 164 | 788 641 |
| C.V. | 91 | 151 | 28 | 26 | 34 | 55 | 50 | 59 | 48 | 26 | 79 | 29 |

After Hayasi (unpublished).


1925-41
1951
1956
1960-62
1966-71
1972-73
1974-75
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140°
145°

Fig. 1. Spawning ground and migratory routes of sardine in eight periods between 1925 and 1978.

After Watanabe (1981).

Nakai (1962) noted expansion and shrinkage of distribution range of the fish according to the change of catch. Amount of Japan's catch of sardine increased from 410,000 tons in 1923 to 1,480,000 tons in 1933. Significant fisheries occurred in Korea in 1925, and Coast Range and Sakhaline in 1930. The total catch reached a peak of 2,700,000 tons in 1936 and 1937, of which Korean catch comprised about one million tons. The expansion of the fishing area indicates enlargement of the whole distribution range accompanied with the rise of stock size. One of the major features of the prosperous period of 1925 to 1940 is appearance of widely migrating group of the fish. In the period about 70 percent of sardine eggs were spawned in the Satsunan Area off southern tip of the Kyushu Island, although the spawning activities occurred widely in the waters south of central Honshu (Fig. 1). The eggs and larvae drifted northeastward along the Kuroshio Current, and spent the first year of life in the coastal waters along Shikoku and Honshu Islands. The I- and II-age fish in the second and third years of life lived in the Pacific waters along the northeastern Honshu. A high correlation coefficient between abundance of the immatures in the Pacific waters and abundance of the adults in the following years in the Japan Sea, as well as seasonal shift of the fishing grounds, indicates that the fish migrated to the Japan Sea through the Tsugaru Straits between Honshu and Hokkaido Islands in the autumn and winter of the third year of life. Thus the major distribution range expanded in the Pacific waters at the young and immature stages before and in II-age, and in the Japan Sea at adults stage of III-age and older. Considerable increase of the population size resulted in the delay of growth and maturation. The first maturity occurred at II-age of body length of about 18 cm in the prosperous years, while at almost the same size but at II-age in the following adverse years of and after 1948.

The Kuroshio Current began meandering in and after 1934, and left the coast, most extensively in the middle 1940's, reaching southward Lat. 30°N, and a large-scale cold water mass appeared in the course of drifting route of sardine eggs and larvae. The larval sardines were accumulated in the infertile Kuroshio waters west of the cold water mass (Fig. 2). Due to starvation, the larval stock suffered a mass mortality and the supply of recruitment was cut from the spawing ground to the nursery ground. Eventually the prolific wide migrating stock collapsed and the amount of total catch over the whole sardine area decreased drastically. After the curtailment of population, the spawning stock shrank to become too small to reach the Satsunan Area, and the spawning grounds shifted year after year (Fig. 1).

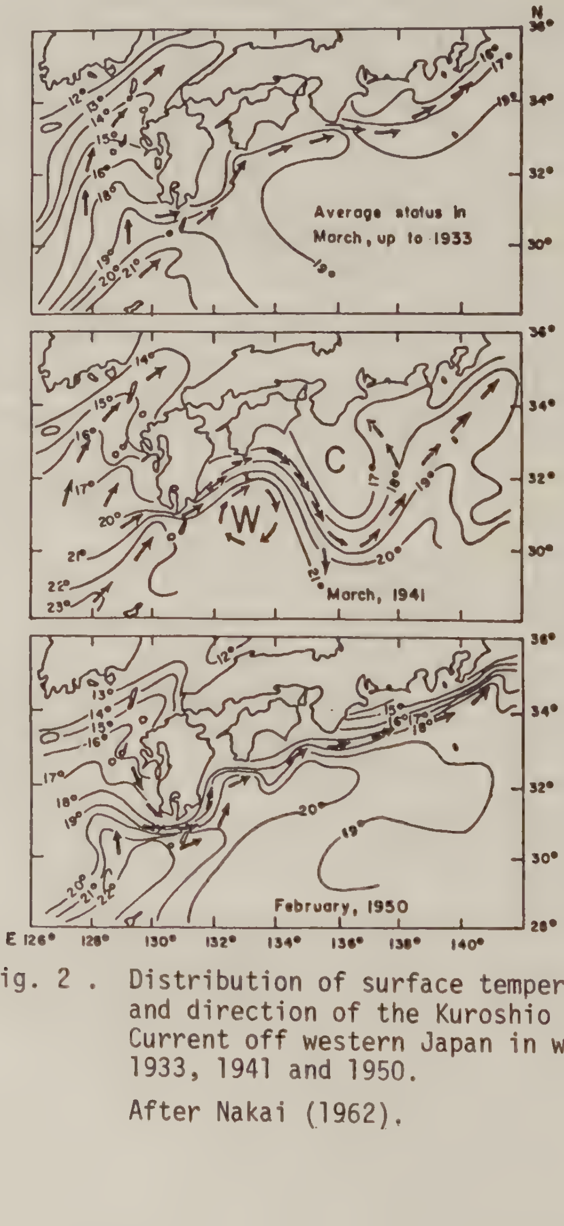

Fig. 2 . Distribution of surface temperature and direction of the Kuroshio Current off western Japan in winter, 1933, 1941 and 1950.

After Nakai (1962).

Nakai (1962) believed that the sardine may spawn in the Satsunan Area off the southern Kyushu when the stock size would become large enough to drive the adult fish to wide migrations, pursuing the food plankton, and then the fish may prosper if they could use the nursery grounds in the highly productive waters off the northeastern Honshu. The reduction of stock size and improvement of efficiency of fishing gear in the 1950's raised the fishing mortality of the sardine. Even though there was no evidence indicating any overexploitation of the population as a whole, it was recommended to prevent the general increase of fishing effort upon the species, and to adopt regulations of fishing in key areas. In 1951 to 1953, the purse seiners exploited significant amount of sardines off western Kyushu which might have seriously disturbed the southward migration to the spawning ground. Thus the fishing operations could have effected the stock size not only due to thinning but also by disturbing migration and spawning. In the 1950's, sardine fisheries became gradually more significant in the Pacific waters along Honshu, together with appearance of remarkable spawning grounds therein. An analysis of catch statistics and the egg census converted to the spawners' stock size in the eleven years from 1950 to 1960 indicated it necessary to avoid intensive exploitation of the dominant year-classes. This proposal was based on the fact that the catch of adults in number varied from 1.1 to 235.3 millions, while the egg abundance remained within a narrower range of 7.04 to 46.87 trillions; and then the rate of exploitation appeared to have sharply risen to about 30 percent when operations upon the dominant classes were very profitable, although it remained less than 5 percent in eight years among eleven. The fishing intensity for three dominant classes which occurred in 1951, 1956 and 1957, was too high to permit these stocks being abundant enough at the adult stage for reproduction of sufficient recruitment. The continuing tendency of increase of stock size was suddenly hampered by cooling of the water in the major spawning ground off the Boso Peninsula of central Honshu in January to May 1963. The anomaly of the temperature reached as much as 14°C in February and March. The drastic cooling caused retardation and southward shift of the spawning activities of sardines (Nakai et al. 1964).

In spite of further decline of the catch in 1963 to 1972 the stock appears to have been on the gradual increase in the central and southern waters off Honshu and Shikoku Islands. Kondo (1980) noted that the Kuroshio Current meandered for the eight years from 1963 to 1971, but flowed near Honshu Island in the spring of 1972 to 1974. The gradually increasing sardine stock had an opportunity to bring strong year-classes in the 1972 and 1974 spawning seasons. Watanabe (1981) explains the shrinkage and recovery of the population on the basis of temperature anomaly and egg abundance.

In the early 1950's a significant stock was found in the East China Sea and Japan Sea along the warm Tsushima Current. The amount of catch as well as eggs and larvae previously expanded there until 1951, but only in the waters west of Kyushu. The waters surrounding the Japanese Islands have been warmed since then, and the spawning grounds shifted northeastward along central Honshu, accompanying delay of spawning season. The northern shift of spawning grounds caused further shrinkage of the nursery grounds, and consequently a rapid curtailment of the stock itself (Fig. 3). Since the major distribution range moved to the Pacific waters in and after 1956, sardine stock increased gradually except the sudden interruption in and just after 1963, and spawning grounds have expanded in the Pacific waters off central Honshu in the early 1970's (Fig. 4). The survival rate in the very beginning stages of life before postlarva was found to be high for the 1972, 1974 and 1975 seasons. The 1972 year-class was a large portion of the stock and produce sufficient recruitment in the following years in spite of fairly concentrated fishing activities. The gradual increase of stock size resulted in the expansion of distribution range, and the spawning retrieved in the Satsunan Area since 1976. Along with this recovery of the historical dominant spawning grounds, the increase of catch from the northward migrants in the feeding phase off the southeastern Hokkaido denotes new expansion of the territory of the sardine population. The westward shift precipitated the spawning season, and then occurrence of the postlarval sardine coincided with the high abundance of copepods' nauplii, thus raising the survival rate of the fish at the early stages of life. Up to 1979, however, the stock size has never reattained the maximum level found in the preceding prosperous phase. The reproduction is still limited within localized sub-populations, and the wide migrants have not occurred yet. Konishi (ms) reported rapid expansion of spawning activities in the Satsunan Area from coastal waters to offshore waters even across the Kuroshio Current during six years between 1976 and 1981, implying that the distribution of eggs and larvae in the offshore water is usual in the expansion phase of the sardine population.

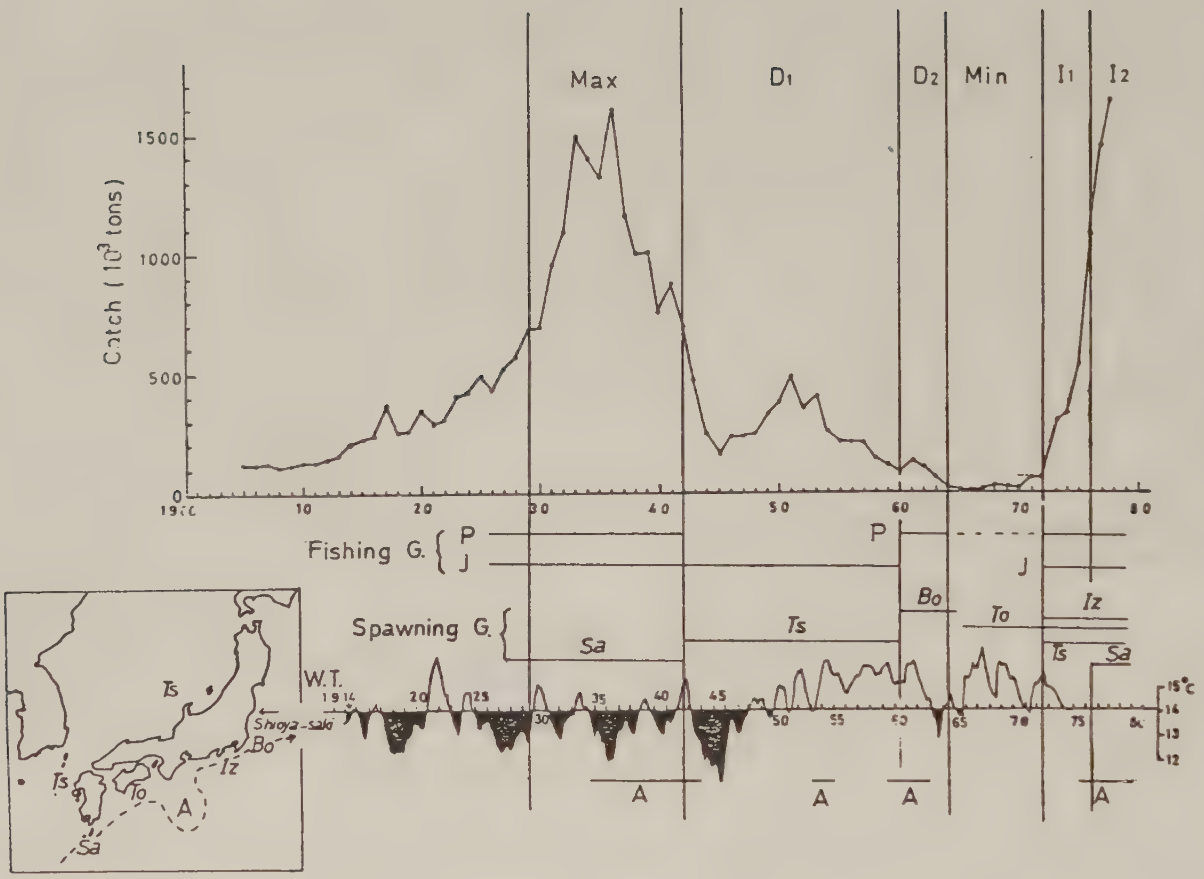

Fig. 3. The catch of sardine in Japan and neighbouring areas, and fishing and spawning grounds in relation to water temperature (W.T.) at a fixed station off Shioya-saki Cape, 1906-1975. Max, D, Min and I denote the maximum, decreasing minimum and increasing periods of catch. "P" and "J" in the entry of Fishing G denote the Pacific waters and Japan Sea with major fishing grounds given by lines. "Sa", "Ts", "Bo", "To" and "Iz" in the entry of Spawning G denote Satsunan, Tsushima Current, Boso Peninsula, Tosa Bay and Izu Islands areas, respectively, with major spawning grounds given by lines. "A"s under short lines for W.T. indicate duration of persistency of the A-type cold water mass that occurred at the position given in the index map.

After Watanabe (1981).

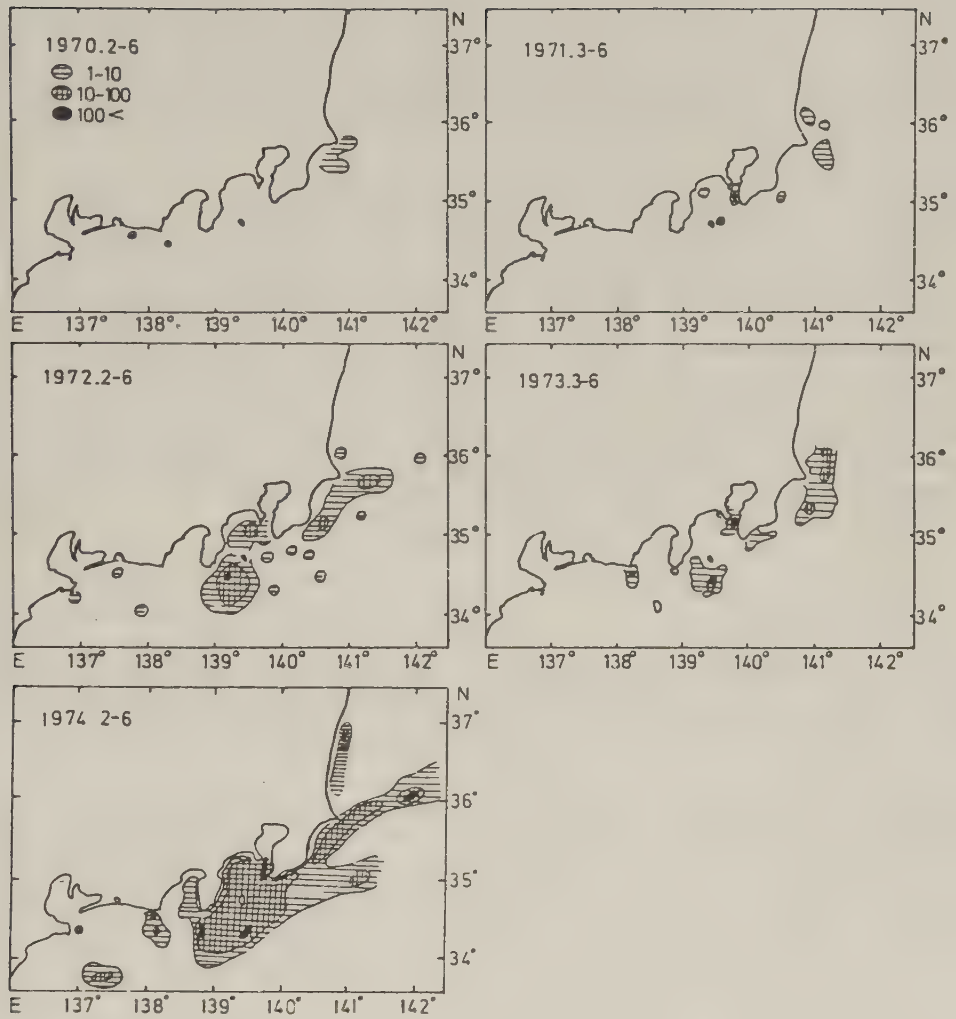
1970.2-6
1-10
10-100
100<
1971.3-6
1972.2-6
1973.3-6
1974 2-6
N
37°
36°
35°
34°
E
137°
138°
139°
140°
141°
142°

Fig. 4. Distribution of eggs of sardine in the Pacific water along Honshu, 1970-1974.

After Watanabe (1981).

Sardine catch in Korea was less than 10,000 tons until 1975, but jumped up to 50,000 tons in 1977 and stayed at significant levels since then. USSR fleet landed the sardine in 1978 to 1980 at a high level of around 300,000 tons (FAO 1975, 1981). This includes the catch made in the waters around the Japanese Islands. All the information indicates recovery of the sardine population and expansion of the distribution ranges.

The other two species of *iwashi* have been quite stable in amount and geographic distribution of catch. Anchovies spawn in the coastal waters to offshore waters throughout the year in the southern waters. Such wide space-time range of reproduction could compensate a failure of recruitment in an area or in a season by that in the other areas or seasons (Hayasi 1962). It could be easily understood that *shirasu* fisheries aim at postlarvae of either sardine or anchovy whichever the species is abundant, and then that the amount of catch has been fairly stable.

Mackerels, jack mackerel and scads also show appreciable variation in amount of catch. Geographically the jack mackerel and scads were more abundant in the East China Sea and Japan Sea than in the Pacific neritic waters. The major fishing grounds of common mackerels shifted from year to year; most abundant in the East China Sea and western Japan Sea in 1953 to 1955 but in the Pacific waters along Honshu in 1956 to 1968. The catch rose in the East China Sea in 1969. For the 1970's products of mackerels are almost the same in the Pacific waters and in the East China Sea and Japan Sea. The catches started a rapid decline in the Pacific waters since 1980, but stayed high in the Tsushima Current area. The fluctuations in these species are not explained yet in spite of recent intensive national and international scientific effort. Although China, Korea, USSR and other states are producing significant amount of these scombroids, the Japanese share is stabilized at 70 to 80 percent (FAO 1975, 1981).

## Pacific herring

Significant fisheries have existed for herring on both western and eastern sides of the northern North Pacific. The fishery had been dominatingly important in the northern Japan, and the Hokkaido Fisheries Experimental Station conducted extensive surveys of the species since its establishment in 1902 (Motoda and Hirano 1963).

The fishery was initiated in the 16th Century, and covered almost the entire coast of Hokkaido Island and northern Honshu Island in the 19th Century. The landing reached a peak of 975,000 tons in 1897, when a stock called "Hokkaido spring herring" had supported the fishery. The spring herring continuously declined in the 20th Century. The recent statistics indicate that the herring has been most abundantly taken in the USSR waters that produced 78 percent of the total catch in the northwestern Pacific Ocean. The USSR catch also decreased from 350,000 tons in 1970 to 57,828 tons in 1978 with slight recovery to 70,000 tons in the following two years (FAO 1975, 1981). The commercial exploitation of herrings by Japanese and Russian fisheries has been abstained in various parts or from various local stocks in the northwestern Pacific Ocean (Morita 1982).

Motoda and Hirano (1963) described ecological changes of the spring herring from 1907 to 1960 when the catch decreased continuously. During the prosperous years, herrings of this stock used to appear in the Japan Sea off Hokkaido in February and March. Then the fish migrated southward, and entered into the coastal waters for spawning. The spawning area shrunk northward, and the growth rate rose together with decline of catch. The age of first maturation decreased from three years to two years, and abnormal eggs were more frequently observed in the spawning beds than before. It is assumed that the spring herring stock had declined due to change of migratory routes of the spawners as a result of drastic and wide environmental variation in the northern Japan Sea and Okhotsk Sea, and even over the North Pacific Ocean. The most probable cause is the rise of water temperature off the entire coast of Kollaido since the years around 1932 to 1938, more evidently in and after 1955. The decline of stock size seemed to have resulted in the spring herring becoming a localized stock occurring year round in the waters along the west coast of Hokkaido.

## Pacific saury

Amongst the wide distributions range over the northern Pacific Ocean, the fishing activities of sauries occur in the limited waters around the central Kurile, southeastern Hokkaido and northeastern Honshu. The operations are mostly concentrated in a short period of the year from September to November. Wide fluctuations in amount, geographical distribution and size composition of the available stocks required extensive studies to find out any means useful for obtaining a pre-season forecast.

Recently Fukushima (1979) investigated long series of catch and effort statistics, biological data including distribution and maturity, and oceanographic information obtained from 1950 to 1970, after the saury fishermen introduced the presently used stick-held dip net with attracting lamps, known as *bouke ami*. This type of fishing technique allowed rapid expansion of the fishing ground toward offshore waters, and rose the amount of catch drastically to a level of 287,648 tons in the annual average between 1953 and 1980, from a lower level of about 30,000 tons in the preceding drift net operations of 1906 to 1949. The fishing grounds of Japanese boats cover a range west of Long. 153°E, and south of Lat. 44°N. Russian fishermen operate the same gear in the northern area above Lat. 45°N (Sablin and Pavlychev 1981).

Sauries of the northwestern Pacific Ocean spawn in the Kuroshio Front and south along the Japanese Islands. The spawning activities last from October off eastern Honshu to the following May off Shikoku. Young and adult fish migrate through the waters off northeastern Honshu in April and May along branches of northwardly expanding Kuroshio Current, and either into the Oyashio Front in June, and then traverse the Oyashio Front and aggregate south of the Kurile Front. In early and middle July large-sized fish of 30 cm in modal length immigrate the northern part of distribution range, reaching as north as Lat. 47°N to Lat. 50°N. Low temperature and rapid change of day length in the northern limit accelerate sexual maturation of the fully grown fish, and drive them to the spawning grounds. Medium- and small-sized fish of 27 to 28 cm or less in modal length are sexually immature in the summer, and continue northward feeding migration until the lowered temperature drives the fish to southward migration in August. In early and middle September, major fishing grounds form off eastern Hokkaido and northern Honshu, north of Lat. 38°N over a projection of the Oyashio Intermediate Front. A warm water mass frequently occurs around southeastern Hokkaido in the month, and often alters position of the Intermediate Front, and then the fishing grounds (Fig. 5). The pronounced warm water mass drives sauries toward offshore waters. When the water mass is weak, good fishing sites occur in the nearshore waters (Fig. 6). In areas without the intermediate water the fish move quickly and are not easily attracted by the fishing lamps. Most fish leave the northeastern Honshu in the late November, and the stick-held dip net fisheries cease their operation. In the winter, the majority of fish enter into the waters around the Kuroshio Current and the Counter Current, north of the sub-tropical convergence.

Because the warm water mass off the southern Kurile Islands near the boundary between Japan and USSR determines the position of the best fishing grounds at the beginning of fishing season, the international proportion does not stay constant year after year, the Japanese catches having comprised 56 to 83 percent of total production (FAO 1975, 1981). Success of fisheries depends on the size of individual fish, abundance and distribution of the available stocks. There are three general size groups, large-sized fish around 30 cm in modal length, medium-sized fish of 26 to 28 cm, and small-sized fish of 24 to 25 cm. The relative abundance of these three groups varies remarkably. Off the northeastern Honshu the fishing grounds form near the coast in the years when the first branch of the Oyashio Current, the nearest flow from the coast, develops intensively, making the operations highly profitable with less time required for cruises of fishing boats. Thus the amount of catch raises in the years when both large- and medium-sized fish are available for fisheries and the nearshore first branch of the Oyashio Current develops (Table 2). Odate and Hayashi (1979) demonstrated correlations between the abundance of larvae and the amount of catch in nine years from 1969 to 1977. The relationship also provides a basis of the pre-season forecast.

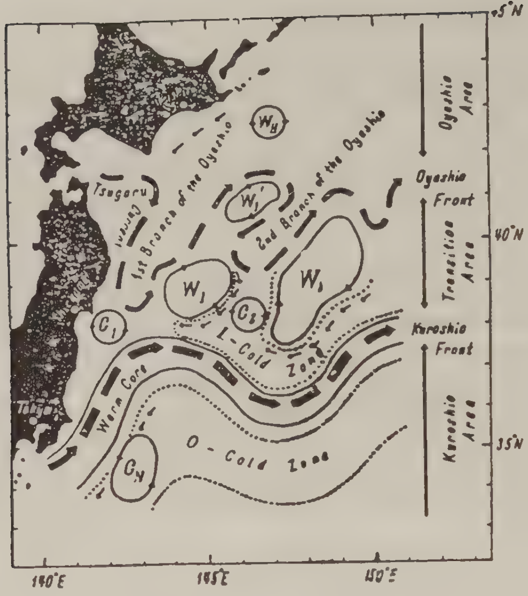
45°N
40°N
35°N
140°E
145°E
150°E
Oyashio Area
Oyashio Front
Transition Area
Kuroshio Front
Kuroshio Area
Tsugaru
Current
1st Branch of the Oyashio
2nd Branch of the Oyashio
$W_H$
$W_1'$
$W_1$
$W_2$
$C_1$
$C_2$
$C_N$
I - Cold Zone
Warm Core
O - Cold Zone
Tokyo

Fig. 5. Schematic presentation of hydrographic conditions in the vicinity of the Polar Front, with zonal structures.

$C_N$: Cold water mass off Nozima-zaki Cape at Lat. 34°54'N, Long. 139°52'E.

$W_H$: Warm water mass off Hokkaido Island.

$W_1$, $W_2$. $W'_1$, $C_1$ and $C_2$: Warm and cold water masses in the transition area.

I.-Cold Zone: Inner cold zone.

O.-Cold Zone: Outer cold zone.

After Kawai (1955).

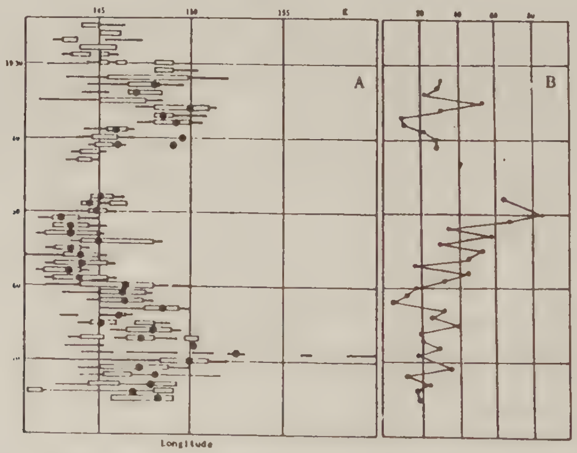

Fig. 6. General longitude position of the major fishing ground of Pacific saury at the beginning of stick-held dip netting season given in bars and rectangles, and of the major flow of the Oyashio Current given in closed circles in the left Panel A, and the extent of area of the coastal first branch of the Oyashio Current given in number of latitude and longitude 20 minute squares identified as such by temperature of 5°C or below at 100 m depth layer.

After Fukushima (1979).

Table 2. Amount of catch of Pacific saury in Japan related with position of northern tip of the Kuroshio Current, general features of the Oyashio Current, position of major fishing areas and dominant size group of individual fish in the commercial catch.

| Northernmost path of the Kuroshio | Trend of the Oyashio | Major fishing area | Dominant size in catch | Amount of catch (Typical years) |
|---|---|---|---|---|
| 38°00′N | The 1st branch develops | Coastal<br>Long. 142°E–145°E | Medium-sized fish<br>(27–28 cm) | 200 000<br>(1950–1953) |
| 37°30′N | The 1st and 2nd branches develop | Coastal and nearshore<br>Long. 142°E–146°E | Bimode of large and medium-sized fish<br>(30 cm and 27–28 cm) | 400 000<br>(1955–1959) |
| 37°00′N | The 1st branch is weak, and the 2nd branch develops | Offshore<br>Long. 144°E–148°E | The same as above but some change in the medium-sized fish<br>(30 cm and 26–27 cm) | 300 000<br>(1960–1963) |
| 36°30′N | The 1st branch is weak, and the 2nd and 3rd braches develop | Offshore<br>Long. 145°E–149°E | Large in even years or medium in odd years for 1964–1967, or large in odd years or medium in even years for 1972–1975 | 200,000<br>(1964-1967 = 1972-1975) |
| 36°00′N | The 1st and 2nd branches are weak, and the 3rd branch develops | Offshore<br>Long. 145°E–151°E | Principally small fish<br>(24–25 cm) | 100 000<br>(1968–1971) |

After Fukushima (1979).

## Flying squids

Okutani (1977) reviewed papers dealing with cephalopods exploited in Japan. The study of stock assessment has been concentrated to the most prolific common flying squid, of which amount of catch showed fluctuations at interval of nine years. The average catch for each interval has shown a gradual decrease. Kitano (1979) noticed that years of low catch, i.e., 1910, 1919, 1928, 1937, 1946, 1955, 1964 and 1973, for 78 years appeared exactly one year after a minimum temperature in 1909, 1918, 1927, 1936, 1945, 1954, 1963, and 1972. He also proposed a minor periodicity with another interval of 4.5 years. The recent statistics indicate the minimum in the 1950's occurred in 1956 but not in 1955. The discrepancy, however, may not seriously affect his conclusion.

After decline of the common flying squid, Japanese fishermen have exploited several other neritic squids. Of these species, *Ommastrephes bartrami* (Leuseur) or *aka-ika* in Japanese language, is the most successfully exploited and the amount of production reached 17,000 tons in 1974, and 188,000 tons in 1980. Murata and Shimadzu (1982) tried to evaluate the stocks off the southern Hokkaido and estimated the rate of exploitation exceeding 30 percent. Even though the estimates are not yet fully reliable, the gradual decline of catch per unit of effort and diminishing of size of individual squids appear supporting an inference that the fishery might have already asserted serious effects upon the stocks.

## CONCLUSIONS

It is widely accepted that the pelagic species are very vulnerable to the intensive exploitation in various parts of the world (Saville 1980). At the same time the environmental anomaly has been known inserting remarkable influence upon these stocks. In the northwestern Pacific Ocean there occurred considerable changes of the abundance and distribution of major pelagic stocks due to environmental anomalies. In such cases it is required to regulate the fishing activities for assisting the recovery of the stocks. Because many fisheries in the area depend on various neritic-pelagic resources of more than one species, it is essential to identify key areas for assuring the effective implementation of fishery regulation for the problem species without hampering exploitation of the other fishes. The identification of key areas requires a thorough knowledge of ecology of the species populations in question.

Unfortunately the existing knowledge is quite insufficient for any species in the northwestern Pacific Ocean. Only the drastic decrease of sardines in the 1940's is fairly well documented, and the recent recovery appears to support the previously proposed hypothesis about fluctuation among the species. The intensive investigations having covered both the commercial catch and distribution of the fish in the sea, especially at the egg and larva stages, since the rise of the sardine stock in the 1930's have efficiently contributed to the advance of biological understanding. Furthermore, the ecological features of sardines make the investigation for this species easier than for the other species. The sardines live and spawn in the limited coastal waters delineated by two distinct warm currents, the Kuroshio Current in the Pacific waters and the Tsushima Current in the East China Sea and Japan Sea, both acting as natural barriers of many neritic-pelagic fishes. The strong demands for these prolific stocks stimulated development of various types of fishing gears which exploit the fish at different stages of life.

As mentioned, the sardine population showed obvious ecological variation in response to changes of the environment and also of the population itself. The increase of population size caused shortage of food organisms and some other necessities as shown by retardation of growth and maturation. In order to adapt such shortage the sardine population expanded their distribution range, and eventually the widely migrating subpopulation appeared, the distribution range of which was delineated in the Satsunan Area, which is located near the dividing point of the Tsushima Current from the major axis of the Kuroshio Current. Once the fish spawn in the Satsunan Area, the eggs and larvae are transported to the Pacific waters along Shikoku and Honshu Islands. Off the northeastern Honshu and southeastern Hokkaido the cold Oyashio Current forms a highly productive mixing zone with the Kuroshio Current, which is characterized by high standing crop of zooplankton (Odate 1980).

It is not well understood yet why the adults moved from the Pacific waters to the Japan Sea through the Tsugaru Strait in the past prosperous years. Although the adults originated in the Japan Sea emmigrated into the Pacific waters in 1956 and 1957 of the adverse period (Hayasi 1960), remarkable migration of adults toward the Japan Sea did not occur yet in the recent years of increasing stock size. It is still uncertain whether this indicates that the present stock size has yet to recover to the previous level or that the exceedingly large amount of catch was achieved by the recent intensified fishing activities. The wide migrants in the past prosperous years might have supported the high production of the species as far as the environmental conditions assure the shift of habitats during the life history. The stock can utilize the warm spawning grounds which accelerate development of the fish at the very beginning stages of life and the highly productive nursery grounds in the mixing zones which provide sufficient food stuff for the enlarged stocks. But the separation of spawning and nursery grounds makes the population vulnerable to environmental changes, especially the significant meandering of the Kuroshio Current in the spawning seasons.

Occurrence of wide migrants was also known in the Pacific herring in the prosperous years. Such ecological changes could exist in common mackerels which have also shown remarkable year-to-year changes of the major fishing and spawning grounds together with variation in amounts of catches. In order to clarify the mechanisms underlying such ecological changes, it is necessary to conduct intensive, direct observations of the fish populations and environmental factors in addition to collection of the relevant data from the commercial fisheries.

Fairly regular cyclic changes were noted in the amount of catch of Pacific saury and common flying squid. They are short-lived species with life span of at most two years. The aforementioned biological data by the direct observations are required for understanding of the periodicity of stock size beyond statistical description. At present, however, there exist gaps between the data requirement and the execution of surveys. The wide expansion of spawning grounds beyond the Kuroshio Current makes it difficult to identify and evaluate quantitatively the spawning activities of the Pacific saury. It is expected that technical development could provide useful means to overcome such difficulties soon in the biological surveys. In the intensively fished areas, it is essential to predict the change of stock size due to environmental causes for the actual benefit to fishing operations. Moreover, such prediction is necessary for achieving rational utilization because similar fishing intensity can deplete seriously "naturally" reduced stocks, even if very practical for "healthy" stocks.

There are two general patterns of fluctuation in major pelagic resources. One is represented by the sardine that showed a wide variation in amount of catch for long-term ranging between 9,215 tons in 1965 and 2,197,744 tons in 1980 and the ratio of the maximum catch to the minimum reached 238:1, but the figures in the successive years do not differ much and do show monotonous decrease or increase. The Pacific saury is an example of the other. The catch ranged within 63,288 tons in 1969 and 575,087 tons in 1958 with the maximum/minimum ratio of 9:1. But the catch often showed fairly large changes year after year. The most typical case is a sudden rise from 196,615 tons in 1972 to 406,445 tons in 1973, and a fall to 135,462 tons in 1974. Sardines enter into fisheries during at least four years from the last half of their first year of life to the fourth year, while sauries live only one or two years. The total stock size depends upon the strength of a single year-class in the saury fisheries, but variations of individual year-classes are "smoothed" away in the sardine fisheries. Instead, the extensive variation ecology occurs together with drastic change of abundance in the sardine population, while a more stable life pattern is retained in the saury population. Most of long-lived species such as herring and common mackerels showed extensive change of fishing grounds as well as amount of catch for long periods of years, but year-to-year change is rather small and predictable on the basis of age composition of catch. Anchovies and flying squids are other examples of short-lived species which vary remarkably on short-term but stays at fairly stable levels over the long-term.

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# STOCK ASSESSMENT OF COMMON MACKEREL AND JAPANESE SARDINE ALONG THE PACIFIC COAST OF JAPAN BY SPAWNING SURVEY

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## Resumen

En relación con las amplias fluctuaciones de la abundancia de recursos pelágicos-neríticos alrededor de Japón, cabe mencionar que desde 1949 se vienen realizando a nivel nacional reconocimientos de huevos y larvas. Se presenta el método de evaluación del recurso por reconocimientos de huevos y larvas que se aplica actualmente en Japón, así como los resultados de obtenidos para dos principales stocks de peces pelágicos-neríticos de la costa del Pacífico de Japón, la caballa común y la sardina Japonesa.

Primero se estimó el número total de huevos desovados en el mar a partir de los datos de abundancia de huevos colectados por muestreo. A partir del número total de huevos se estima el número total de peces desovantes, lo cual se hace con la ayuda de información biológica y datos de la captura. Si existe información de la composición por edades (y de la captura comercial) se puede estimar tanto la abundancia del stock desovante como de los juveniles. Del examen de la relación entre el stock desovante y el reclutamiento se puede estimar la magnitud de desovantes que tienden a mantener la abundancia del stock a un nivel adecuado.

### Caballa Común

Hay un sólo stock de caballa común en la región, la sub-población del Pacífico. La magnitud del stock desovante tuvo un nivel extremadamente bajo hasta mediados de los años 1950s (alrededor de 30 x $10^{12}$ huevos desovados) y de ahí comenzó a aumentar marcadamente, con dos máximos entre 1962-64 (650-780 x $10^{12}$) y en 1974-76 (1 x $10^{13}$). Luego mostró una tendencia declinante con valores alrededor de 270 x $10^{12}$ en sus años recientes.

Las nuevas clases anuales que fueron sumamente débiles en 1948-52, también mostraron un continuo incremento en los años sucesivos, alcanzando dos máximos en 1961 y 1972. Estos declinaron a mediados de los años 60 y mediados de los años 70. Se asume que la disminución en la abundancia del stock fue mayormente el resultado de la marcada reducción del reclutamiento. Sin embargo, es probable que la pesca haya acelerado esta disminución, especialmente por la captura de peces juveniles (edad 2) de clases anuales débiles mediante el uso de artes de pesca no selectiva como la red de cerco.

Durante los dos períodos en que se ha observado un incremento de la abundancia del stock, se ha observado una función dependiente de la densidad en la curva stock-reclutamiento a la cual se ajustan dos diferentes curvas del tipo de Ricker. Esto sugiere que el marcado incremento de la abundancia de las nuevas generaciones, que eran mucho más abundantes que las del stock paterno, haya resultado en un rápido incremento del stock total durante el período de expansión. Sin embargo, la abundancia de reclutas disminuyó marcadamente cuando la población alcanzó un nivel extraordinariamente alto. Después de una serie de reclutamientos bastante bajos el stock total disminuyó drasticamente.

De las curvas de reproducción obtenidas se estima que la magnitud de desovantes (expresada en número de huevos producidos) es de 400 x $10^{12}$, y que el número mínimo requerido para preservar el stock es 200 x $10^{12}$. A juzgar por la información disponible se espera que el stock comience a aumentar en un futuro cercano. Sin embargo, si la pesca comercial causa una reducción masiva de los peces juveniles es probable que la abundancia del stock decline más todavía.

## Sardina Japonesa

Hay dos stocks de sardina Japonesa a lo largo de las costas del Pacífico de Japón. La sub-población del Pacífico en la región norte y centro y la sub-población de Ashizuri más al sur.

La magnitud del desove en la sub-población del Pacífico se ha mantenido a un nivel bajo (10-20 x $10^{12}$ huevos producidos) hasta inicios de la década de los años 70. A inicios de los años 60 se produjo un aumento temporáneo (hasta 200 x $10^{12}$). El desove aumentó desde 1972 con un pico máximo de 580 x $10^{12}$ en 1978, de donde se generó el explosivo aumento de la población en la segunda mitad de la década de los años 70. El stock disminuyó nuevamente, y en años recientes la magnitud del desove se encuentra alrededor de los 150 x $10^{12}$ huevos producidos.

En este caso también se observa una función dependiente de la densidad durante el período de incremento, a la cual una curva del tipo de Ricker se ajusta bien. Se estimó que el nivel de desove deseable para mantener el stock es de 150-250 x $10^{12}$.

El área de desove de la sub-población de Ashizori se encuenta más al sur, aguas arriba en la corriente de Kuroshio. La magnitud del desove de este stock también aumentó marcadamente desde 1978 y sobrepasó en abundancia a la sub-población del Pacífico en años recientes. La sub-población de Ashizuri alcanzó su máximo en 1982, con un desove de alrededor 360 x $10^{12}$ huevos. Aparentemente una cantidad significativa de larvas de esta sub-población habrían sido transportados por la corriente de Kuroshio y se habrían reclutado a la sub-población del Pacífico.

Se asume que el stock de sardina a lo largo de la costa del Pacífico extiende su área de reproducción hacia el sur durante períodos de próspero crecimiento. La magnitud combinada de estas dos sub-poblaciones parece haberse mantenido a niveles bastantes altos en años recientes.

## Relaciones Caballa - Sardina

Los procesos que han resultado en cambios en la abundancia parecen ser bastante análogos en ambas especies, lo que puede ser debido a las semejanzas en la forma de vida y el hábitat de estas dos especies. Esto sugiere que ambos stocks han mantenido un potencial intrínseco para aumentar explosivamente aún en los períodos de depresión. Con esto los stocks pueden fácilmente recuperarse cuando el ambiente cambia y se dan las condiciones favorables para la sobrevivencia de los primeros estadios de la vida.

Un aspecto característico observado en el stock de sardina fue la expansión del área de desove corriente arriba de la corriente de Kuroshio. Esto puede haber permitido que el stock realice una biomasa extraordinariamente alta, excediendo el factor espacial limitante que habría sido impuesto en una sóla sub-población. Con el stock de caballa no se ha observado esta deformación estructural. Sin embargo, ambas especies han ampliado su hábitat, ampliando su distribución al máximo posible, durante los períodos de prósperidad.

Por otro lado, a niveles extremamente altos de la abundancia se presenta el efecto negativo dependiente de la densidad, lo que puede dar por resultado una menor variabilidad de huevos y larvas y la eventual disminución del reclutamiento. El stock puede disminuir y disminuirá nuevamente si se presentan condiciones ambientales desfavorables.

Se concluye que los stocks de caballa y sardina en la costa del Pacífico de Japón tienen requerimientos ambientales similares, y que aún cuando las condiciones favorables y desfavorables se dan alternativamente a intervalos de varios años en la misma región, cada especie tiene su propia dinámica.

## INTRODUCTION

The major neritic migratory pelagic fish resources around Japan such as common mackerel, Japanese sardine, anchovy, jack mackerel, herring and saury have repeatedly shown long-term large changes in abundance. Dramatic changes in dominance have also occurred among these species. Clear explanations of these phenomena have not been made so far. However, it has been generally accepted that changes in the magnitudes of recruitment in connection with changes in environmental conditions have played an important role though reductions by commercial fishing might have affected them in some cases, especially during the declining period of the stocks. Spawning surveys are among the most effective ways of clarifying phenomena occurring among the reproductive segments of fish life histories.

These species spawn floating pelagic eggs when the adults aggregate on spawning grounds during their spawning seasons. The eggs spawned and the hatched larvae drift on the surface or in the near-surface layer of the sea for a certain period. They are gradually dispersed over wide areas of the sea, dependent on the movement of the water masses, and grow during the drifting period. Japanese flying squid though has a different life history form from those of neritic pelagic fish, but also experiences the same patterns during the egg and larval stages. Taking advantage of the distribution patterns of eggs and larvae, as mentioned above, a quantitative survey of their abundance can be made by a sampling method at suitably designed survey stations using standardized methods and plankton/larva nets.

A nation-wide spawning survey network for the above-mentioned purpose was established in 1949, and intensive observations have been carried out since then on the distribution and abundance of eggs and larvae, physical and biological environmental conditions at each of the survey stations. The major outcomes expected from the survey are: (1) details on the life history form and the abundances of stocks before commercial fishing, (2) information on the major factors involved in the annual change in recruitment and, accordingly, predictions of the magnitudes of recruitment to exploitable stocks in the forthcoming fishing season, (3) the assessment of the stocks concerned through qualitative analysis of data collected by the survey and by the existing fisheries, (4) the estimates of the total amount of allowable catches to be imposed on the commercial fisheries with the aim to maintain the stock abundances at a favourable level in terms of future reproduction and (5) the prediction of the long-term trends on changes in stock abundance.

The author presents, in this paper, the techniques which are currently employed in the spawning survey in Japan and the results of the application to the stock assessment of the two major neritic pelagic fish stocks along the Pacific coast of Japan - common mackerel and Japanese sardine.

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## TECHNIQUES EMPLOYED

The principles applied in the spawning survey are rather simple and clear - sampling methods and back-calculations - and those techniques have already been well established (Tanaka 1955a, 1955b, Nakai 1962, Nakai et al., 1955, 1962, Watanabe 1970, 1972).

### Abundance of eggs spawned

Spawning surveys in Japan are being carried out by a standardized method (a perpendicular tow from 150 m deep to the surface of the sea) with a standardized plankton net (60 cm or 45 cm opening diameter with 0.33 mm mesh size) to maintain a consistency of the data basis. The designation of the survey stations is carefully made in order to fully cover the areas concerned and has become fixed over the years. The timing and the duration of the survey in each year are also designed to fully cover the spawning season of each species while the most intensive observations are usually concentrated in the spawning grounds during the spawning season of each species. An example of the data collected by the spawning survey for common mackerel along the Pacific coast of Japan is shown in Figure 1.

The total number of eggs spawned in the area concerned during the entire spawning season is firstly estimated from the observed egg abundance (density) of the sampling survey. If the sea-area is stratified into two strata (medium: i, smallest : j), which is usually subdivided by geographic and oceanographic conditions of the area in conjunction with the location and extent of the spawning ground in the area, and if the egg abundance ($E_i$ : average number of eggs observed per 1 $m^2$ by month) is obtained in an $A_i$ $m^2$ area in the j-stratum, the apparent total number of eggs to be observed in a unit area in the j-stratum in the month is given by

$$\sum_j E_j \cdot A_j$$

The total number of eggs spawned in an i-stratum area in a month ($E_i$) is then estimated by adjusting the above estimate with the escapement from egg by hatching and the loss by natural mortality during the egg stage as

$$E_i = (1/S \cdot D/d_i)\sum_j E_j \cdot A_j$$

where S : survival rate during the egg stage
D : number of days in a given month
$d_i$: average number of days required for hatching in a given i-stratum area

The total number of eggs spawned in the entire area concerned in a month (E) is accordingly estimated to be

$$E = \sum_i E_i = (D/S)\sum_i (1/d_i)\sum_i E_j \cdot A_j \qquad \text{....(1)}$$

and the variance of the estimate (V(E)) to be

$$V(E) = \sum_i (1/S \cdot D/d_i)^2 \sum_j A_j^2 \ v_j \qquad \text{....(2)}$$

where $v_j$ : variance of $E_j$ in a j-stratum area.

### Parental stock abundance and parameters

If the age-composition of the commercial catch is available to represent the age-structure of the stock, the total number of eggs spawned in a given year (E) can be divided into the numbers to have been spawned by the parental (adult) fish by age (i) with the aid of the biological information as

$$NE_i = E \cdot (c_i \cdot n_i)/\sum_i c_i \cdot n_i \qquad \text{....(3)}$$

where $NE_i$ : number of eggs spawned by i-age fish
$c_i$ : ratio of the number of i-age fish in the total adult fish catch
$n_i$ : number of eggs to be spawned by a single female of i-age fish.

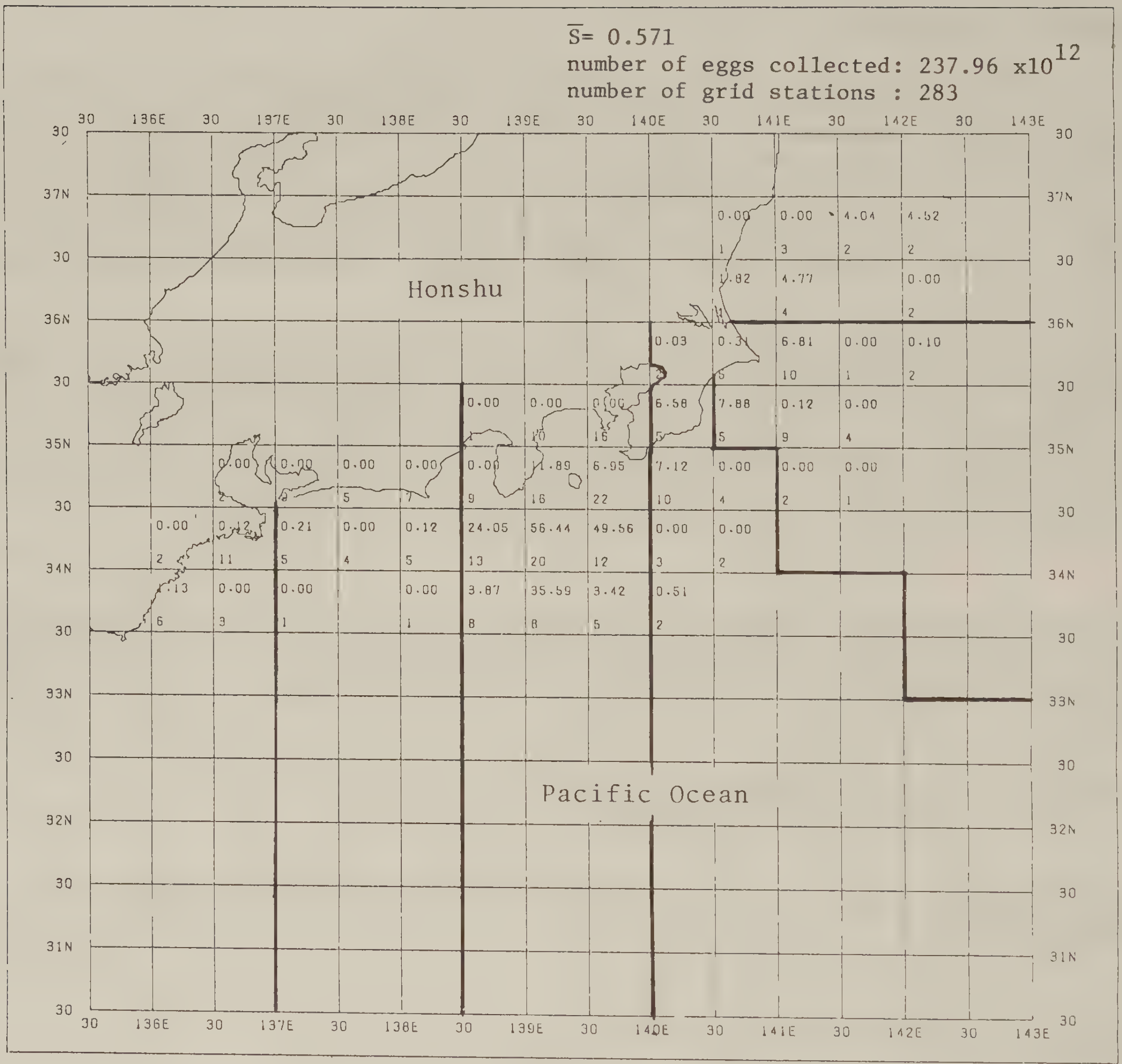
S̄= 0.571
number of eggs collected: 237.96 x10^12
number of grid stations : 283
30 136E 30 137E 30 138E 30 139E 30 140E 30 141E 30 142E 30 143E
30 37N 30 36N 30 35N 30 34N 30 33N 30 32N 30 31N 30
Honshu
Pacific Ocean
0.00 1 0.00 3 4.04 2 4.52 2
1.82 4.77 4 0.00 2
0.03 0.31 5 6.81 10 0.00 1 0.10 2
0.00 0.00 10 0.00 16 6.58 5 7.88 5 0.12 9 0.00 4
0.00 2 0.00 0.00 5 0.00 7 0.00 9 1.89 16 6.95 22 7.12 10 0.00 4 0.00 2 0.00 1
0.00 2 0.12 11 0.21 5 0.00 4 0.12 5 24.05 13 56.44 20 49.56 12 0.00 3 0.00 2
.13 6 0.00 3 0.00 1 0.00 1 3.87 8 35.59 8 3.42 5 0.51 2

Figure 1

An example of the data on the spawning survey of the common mackerel stock along the Pacific coast of Japan. The numerals in each square indicate the number of eggs collected in $10^{12}$ (upper) and the number of survey stations allocated in the square (lower). The survey was carried out in April 1980.

The number of adult (parental) fish by age ($NA_i$) is then estimated taking the sex ratio of female (r) into account as

$$NA_i = 1/r.NE_i/n_i \qquad \text{....(4)}$$

and the total adult stock number (NA) as

$$NA = \sum_i NA_i$$

Similarly, the adult stock biomass by age ($PA_i$) and the total biomass (PA) are

$$PA_i = NA_i.w_i \qquad \text{....(5)}$$

$$PA = \sum_i PA_i$$

where $w_i$ : bodyweight of an i-age fish.

If the total number of the adult fish in the total catch (CA) taken by commercial fisheries is known, the catch rate of adult stock (CRA) is given by

$$CRA = CA/NA = (1 - SA).FA/(FA + MA) \qquad \text{....(6)}$$

where CA : total number of adult fish caught by commercial fisheries
FA : fishing mortality coefficient of adult stock
MA : natural mortality coefficient of adult stock
SA : survival rate of adult stock.

If the age-composition of the adult stock ($NA_i$) is obtained for the age i to j for the successive two years (years t and t + 1), the survival rate of adult stock (SA) can be estimated by the following equation

$$SA = (NA_{i+1,\ t+1} + NA_{i+2,\ t+1} + ....NA_{j,\ t+1})/(NA_{i,\ t} + ....NA_{j-1,\ t})$$

The total mortality coefficient (ZA = FA + MA) is then estimated by

$$SA = e^{-ZA}$$

and accordingly, the fishing and natural mortality coefficients (FA and MA) are estimated by equation (6).

Juvenile stock abundance

If the age-composition of the total catch of juvenile fish taken by the commercial fisheries ($CA_{i-1}$, $CA_{i-2}$....) is available, the abundance of juvenile fish at given ages (i-1, i-2, ....) can be estimated by a series of back-calculations. That is, if the natural mortality coefficient (M) during the juvenile stage is assumed to be the same as that in the adult stage (MA) which has been given by equation (6),the fishing mortality coefficient during the oldest juvenile age ($F_{i-1}$) is estimated by the equation below as

$$CA_{i-1}/NA_i = (e^{F_{i-1}+M} - 1)\ F_{i-1}/(F_{i-1} + M) \qquad \text{....(7)}$$

where $NA_i$ : number of the youngest adult fish in the successive year,

and subsequently, the total mortality coefficient and the survival rate during the same age ($Z_{i-1} = F_{i-1} + M$ and $S_{i-1} = e^{-Z_{i-1}}$). The stock number of the juvenile fish, which is one age younger than the youngest adult fish ($NJ_{i-1}$) is then estimated as

$$NJ_{i-1} = NA_i/S_{i-1} \qquad \text{....(8)}$$

In the case that the survival rate ($S_{i-1}$) is obtainable from the age-composition data of the catch, the stock number could be estimated directly by equation (8). The stock number for the retroactive ages (i-2, i-3, ....) could be estimated through similar back-calculations.

## Total allowable catch

The favourable magnitude of spawning is first estimated, with the aim to sustain the stock abundance at a favourable level in terms of future reproduction. It has been ascertained for the major neritic pelagic stocks around Japan that a density-dependent relationship is observed between the number of eggs spawned by a parental stock and that of the brood, which fit the Ricker-type reproductive curve well. The cumulative number of eggs spawned in a brood during its adult stage (P) is therefore expected to reach a peak at a certain level of the magnitude of parental spawning ($NE_t$ : number of eggs spawned by the parental stock in year-t). That is

$$P = A.NE_t.e^{-B.NE_t} \qquad ....(9)$$

where, A and B are constants. The abscissa value of the peak of the brood against the parental spawning would give the most favourable level of spawning by the parental stock. The abscissa where the brood turns to a sharp decrease in accordance with the decrease in parental spawning may give the minimum or safe spawning level required to prevent deterioration of the stock.

If the desirable or required level of spawning in the next year (t + 1) is provisionally given as $NE_{t+1}$ (number of eggs to be spawned) the desirable/required survival rate in the year-t would be given in terms of the number of eggs, namely, the survival of anticipated eggs over the potential spawning by the provisional adult stock (one-age younger fishes in year-t), by the following equation as

$$S_t = NE_{t+1}/(NA_{i-1,t}.n_i + NA_{i,t}.n_{i+1} + NA_{i+1,t}.n_{i+2} + ....)\, r \qquad ....(10)$$

where

$NA_{i-1,t} = NJ_{i-1,t}$: The number of the provisionsal youngest adult fish in the next year (t + 1) at age-i

$n_i$ : the number of eggs to be spawned by a single adult female of age-i

r : sex ratio of female

The expected total number of adult fish in the next year ($NA_{t+1}$) which should correspond with the anticipated spawning ($NE_{t+1}$) is therefore

$$NA_{t+1} = (NA_{i-1,t}\ \ NA_{i,t} + NA_{i+1,t} + ....)S_t \qquad ....(11)$$

Assuming here that natural mortality coefficient (M) is constant regardless of the age of fish and is known, the fishing mortality for the year-t ($F_t$) is estimated by the survival rate obtained ($S_t$), and accordingly the catch rate of the adult fish in the same year ($CRA_t$), as

$$CRA_t = (1 - S_t)F_t/Z_t \qquad ....(12)$$

The total allowable catch of adult fish in the year-t ($TAC_t$), which corresponds with the desirable/required spawning in the next year ($NE_{t+1}$) is therefore to be

$$TAC_t = (NA_{i-1,t} + NA_{i,t} + NA_{i+1,t} + ..)CRA_t \qquad ....(13)$$

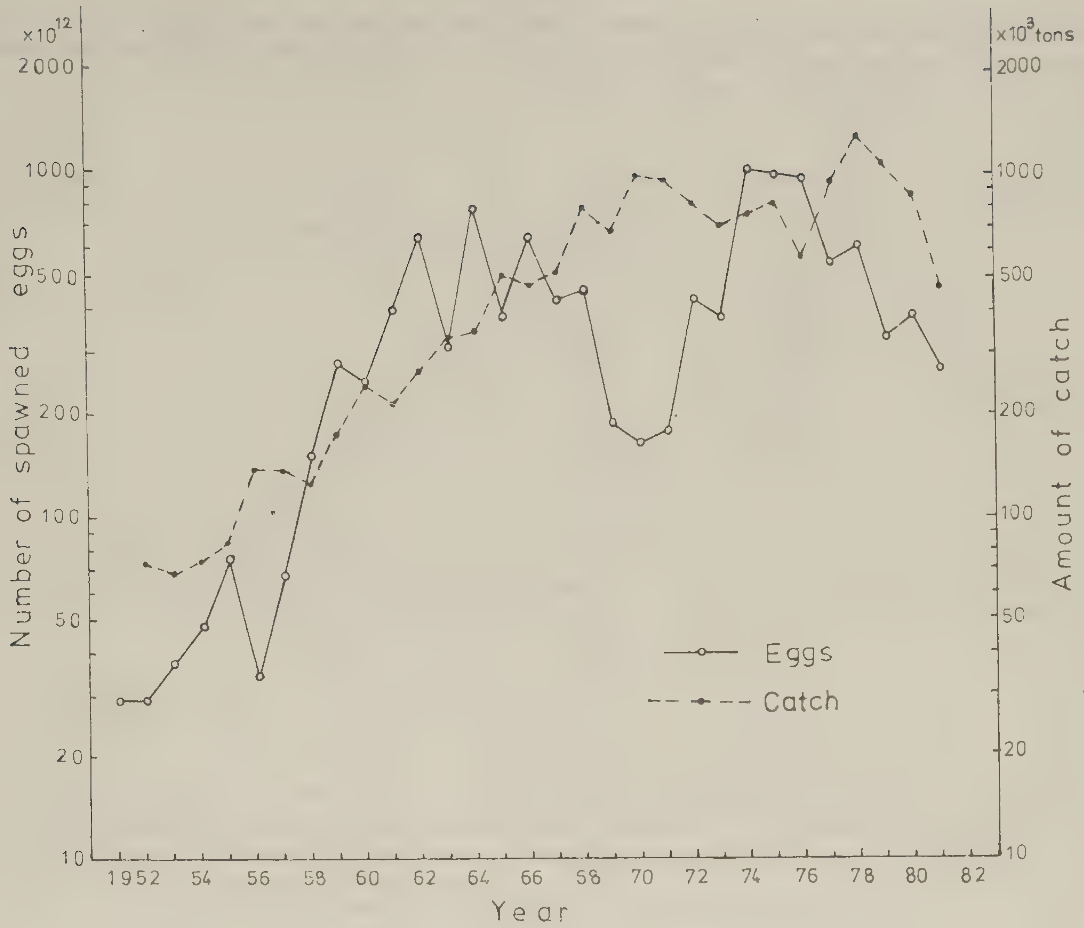

Figure 2

Annual change in the estimated total number of eggs spawned and the nominal catch of the common mackerel stock along the Pacific coast of Japan during 1951-81 (Watanabe, 1977, and supplement).

## STOCK ASSESSMENT

The assessment of the two major neritic pelagic stocks along the Pacific coast of Japan, common mackerel and Japanese sardine, has been made being based on the data collected by the spawning survey.

### Common mackerel

Common mackerel in the region comprises a single stock, the Pacific sub-population. The catch from the stock began to increase in the early 1950's from a low level at about 70-80,000 tons and reached a peak at about 0.95-0.98 million tons during the early 1970's (Figure 2 and Table 1). After a sharp decline down to about 0.6 million tons in the mid-1970's, it increased markedly again reaching the highest with about 1.3 million tons in 1978. The catch shows a declining trend thereafter and was about 0.5 million tons in 1981.

The magnitude of the spawning of the stock increased markedly around the late 1950's from an extremely low level at about 30 x $10^{12}$ in the total number of eggs spawned and reached a peak with 650-780 x $10^{12}$ during 1962-66 (Figure 2 and Table 1). After a temporary but sharp decline down to 160-190 x $10^{12}$ around 1970, it increased again quite remarkably and reached its maximum of 960-1,020 x $10^{12}$ during the mid-1970's. It shows a declining trend thereafter and was about the 270 x $10^{12}$ level in 1981.

## Table 1

Annual change in the estimated total number of eggs spawned and the nominal catch of the common mackerel stock along the Pacific coast of Japan during 1951-81 (Watanabe, 1977, and supplement).

| Year | Eggs Spawned $(10^{12})$ | Catch $(10^3$ tons) |
|---|---|---|
| 1951 | 29 | NA |
| 1952 | 29 | 72 |
| 1953 | 37 | 68 |
| 1954 | 48 | 73 |
| 1955 | 75 | 83 |
| 1956 | 34 | 138 |
| 1957 | 67 | 136 |
| 1958 | 151 | 124 |
| 1959 | 280 | 172 |
| 1960 | 247 | 239 |
| 1961 | 396 | 205 |
| 1962 | 645 | 267 |
| 1963 | 308 | 324 |
| 1964 | 782 | 338 |
| 1965 | 381 | 491 |
| 1966 | 647 | 457 |
| 1967 | 422 | 502 |
| 1968 | 459 | 778 |
| 1969 | 187 | 665 |
| 1970 | 163 | 979 |
| 1971 | 179 | 941 |
| 1972 | 432 | 821 |
| 1973 | 381 | 700 |
| 1974 | 1,024 | 726 |
| 1975 | 986 | 804 |
| 1976 | 962 | 564 |
| 1977 | 548 | 945 |
| 1978 | 616 | 1,270 |
| 1979 | 338 | 1,100 |
| 1980 | 390 | 873 |
| 1981 | 273 | 450 |

NA: Data not available

The year-class strength of spawners (ages 3-6), which had been extremely weak during the 1948-53 year-classes, also showed a steady gain in successive year-classes and reached a peak in 1961 (Figures 3 and Table 2). It declined once during the later half of the 1960's but recovered soon after with a further rapid increase reaching the highest in 1972. The abundance of spawners in recent years, however, shows a sharp declining trend.

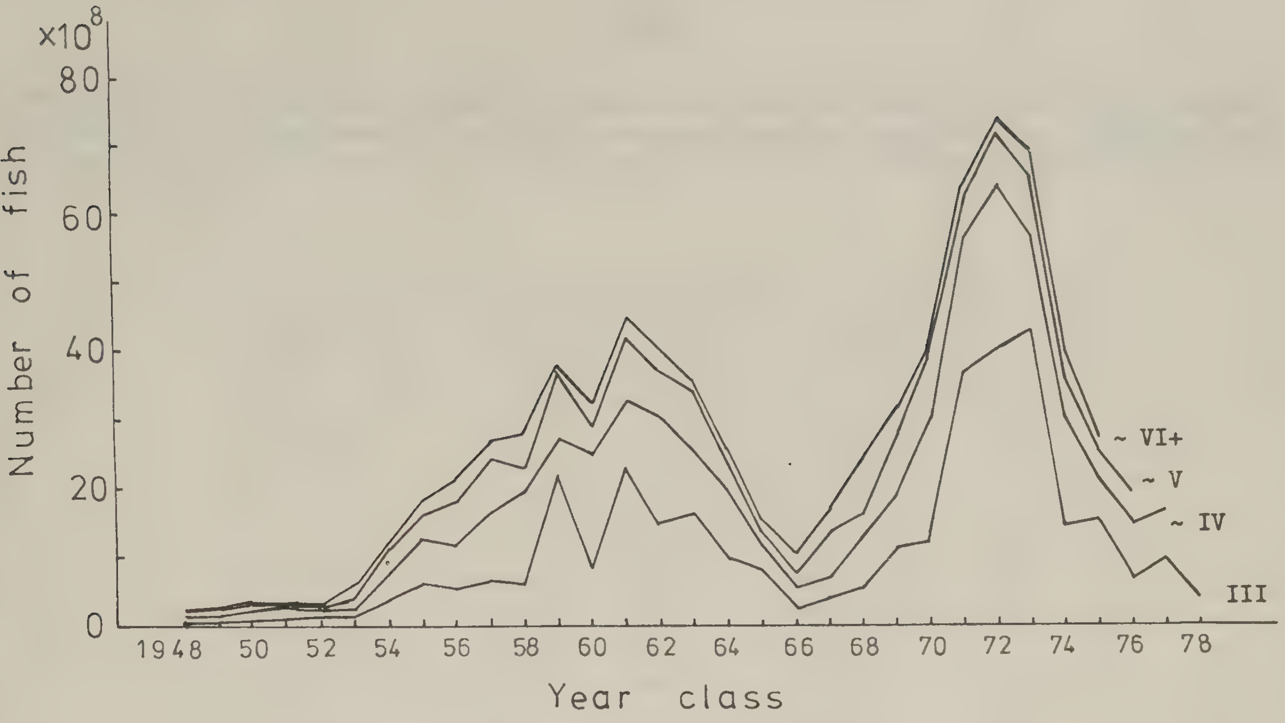

Figure 3

Change in the number of adult fish by age in each of the year-classes of the common mackerel stock along the Pacific coast of Japan for the year-classes 1948-78. The number of fish was estimated from the observed egg abundance. The numbers at age IV and above are shown with the accumulated numbers including those of all the younger ages.

The stock number of the juvenile fish at age-2 was estimated from the catch data (number of fish caught at age-2) and the estimated stock number of adult fish at age-3 for the year-classes 1961 -78. A comparison among the estimated stock number, catch in number and fishing mortality coefficient at age-2 was made (Figure 4 and Table 3). It is interesting to see that the fishing mortality coefficient tends to increase when the stock number decreases. Another notable thing found in the comparison is that the catch and fishing mortality coefficient of the age-2 fish decreased drastically during the early 1970's in contrast to the sharp increase in the stock number. This might have been caused mostly by the low availability of the fish in the northern coastal fishing grounds where a substantial amount of age-2 fish had usually been taken by purse-seiners during the feeding migration of the fish to the north. It is supposed that the fish might have migrated to further off-shore areas during the above-mentioned period probably in connection with the burst of the sardine stock in the coastal areas where intensive fishing on sardine by purse-seiners was carried out.

The relationship between the estimated total number of eggs spawned by the parental stock in each year and that spawned by each of the successive broods during their adult stage (ages 3-5) shows a density-dependent function which fits the Ricker-type reproduction curve well (Figure 5 and Table 4). It is noted that the two different curves are fitted to the two different growing periods of spawning magnitude, i.e. 1951-64 and 1969-74 year-classes respectively. The spawning of broods declined far below the reproductive curves during the imtermediate year-classes (1965-68) of the above-mentioned two year-class groups. Both the curves obtained show that the highest spawning by a brood is expected at about the 400 x $10^{12}$ egg level of parental spawning. The change in the parental spawning during 1969-71 and the reproductive relationship afterwards suggest that even if the spawning of parental stock declined substantially (down to 160-190 x $10^{12}$ eggs), the spawning by broods could soon recover if the environmental conditions remain favourable for a successive few years. It is assumed, however, that a further decline in the parental spawning might be deteriorative as brood spawning decreases precipitously. It is estimated, in this connection, that the 200 x $10^{12}$ level of parental spawning would be the minimum level which would ensure that stock abundance would be kept at a safe level.

## Table 2

Change in the number of adult fish by age in each of the year-clases of the common mackerel stock along the Pacific coast of Japan for the year-classes 1948-78. The number of fish was estimated from the observed egg abundance.

| Year-Class | Number of Fish by Age ($10^8$) | | | |
|---|---|---|---|---|
| | 3 | 4 | 5 | 6+ |
| 1948 | 0.64 | 0.68 | 0.50 | 0.25 |
| 1949 | 0.50 | 0.72 | 0.77 | 0.48 |
| 1950 | 0.80 | 1.16 | 1.25 | 0.15 |
| 1951 | 0.95 | 1.77 | 0.45 | 0.08 |
| 1952 | 1.20 | 0.79 | 0.49 | 0.54 |
| 1953 | 1.18 | 1.15 | 1.61 | 2.04 |
| 1954 | 3.87 | 3.35 | 4.27 | 0.70 |
| 1955 | 6.03 | 6.50 | 3.68 | 2.28 |
| 1956 | 5.20 | 6.32 | 6.84 | 3.15 |
| 1957 | 6.49 | 9.88 | 7.87 | 3.17 |
| 1958 | 5.83 | 13.63 | 3.40 | 5.23 |
| 1959 | 22.02 | 5.21 | 9.89 | 0.95 |
| 1960 | 8.60 | 16.28 | 4.45 | 2.87 |
| 1961 | 23.26 | 9.84 | 9.55 | 2.63 |
| 1962 | 14.93 | 15.76 | 6.72 | 3.31 |
| 1963 | 16.71 | 9.06 | 8.64 | 1.64 |
| 1964 | 9.94 | 9.83 | 3.82 | 2.08 |
| 1965 | 8.02 | 3.74 | 1.95 | 2.00 |
| 1966 | 2.52 | 2.73 | 1.92 | 3.46 |
| 1967 | 4.02 | 2.92 | 6.88 | 3.51 |
| 1968 | 5.48 | 7.47 | 3.51 | 8.50 |
| 1969 | 11.49 | 7.67 | 9.31 | 3.64 |
| 1970 | 12.12 | 18.70 | 10.19 | 1.29 |
| 1971 | 37.41 | 19.70 | 6.34 | 2.08 |
| 1972 | 40.82 | 24.18 | 8.00 | 2.03 |
| 1973 | 43.75 | 13.65 | 8.89 | 4.00 |
| 1974 | 14.72 | 16.57 | 5.07 | 4.14 |
| 1975 | 15.66 | 5.95 | 4.14 | 1.72 |
| 1976 | 6.75 | 8.12 | 4.77 | - |
| 1977 | 9.97 | 7.06 | - | - |
| 1978 | 4.23 | - | - | - |

## Table 3

Change in the estimated stock number, commercial catch in number and fishing mortality coefficient at age-II of the common mackerel stock along the Pacific coast of Japan for the year-classes 1961-78. The natural mortality coefficient was assumed to be 0.5 throughout the period (Watanabe 1977, and supplement).

| Year-Class | Stock Number ($10^8$) | Catch Number ($10^8$) | Fishing Mortality Coefficient |
|---|---|---|---|
| 1961 | 44.14 | 2.32 | 0.068 |
| 1962 | 36.55 | 1.34 | 0.048 |
| 1963 | 36.69 | 1.24 | 0.044 |
| 1964 | 22.29 | 1.47 | 0.087 |
| 1965 | 13.17 | 1.38 | 0.140 |
| 1966 | 6.72 | 2.64 | 0.481 |
| 1967 | 10.44 | 3.06 | 0.455 |
| 1968 | 19.03 | 8.12 | 0.746 |
| 1969 | 26.78 | 6.27 | 0.347 |
| 1970 | 52.64 | 12.91 | 0.367 |
| 1971 | 69.65 | 6.36 | 0.123 |
| 1972 | 72.76 | 4.28 | 0.078 |
| 1973 | 76.22 | 3.24 | 0.056 |
| 1974 | 27.58 | 2.61 | 0.127 |
| 1975 | 37.92 | 9.67 | 0.384 |
| 1976 | 32.61 | 17.63 | 1.074 |
| 1977 | 32.37 | 12.88 | 0.678 |
| 1978 | 10.60 | 2.91 | 0.419 |

The commercial catches during 1977-78 (0.95-1.27 million tons) were well balanced with the estimated annual allowable catch for the period (1.0-1.3 million tons) to maintain the spawning magnitude at a favourable level (400 x $10^{12}$ eggs). However, this level was exceeded in 1979 with 1.1 million tons catch over the allowable catch of about 0.65-0.85 million tons for the year. The allowable catch has become even smaller since 1980 in conjunction with the decline in the spawning magnitude of parental stock. The catch though has also been declining substantially since 1980; catches in 1981 (0.45 million tons) again exceeded the estimated allowable catch (0.27-0.36 million tons) required to maintain spawning at a safe level (200 x $10^{12}$). However, the parental spawning during 1980-81 was still higher than the above-mentioned level with 390-270 x $10^{12}$ eggs though it showed a declining trend (Figure 2 and Table 1) and juvenile fish of the 1980 year-class appeared to be abundantly distributed in many nursery grounds in the region. Provisional information on the result of the spawning survey carried out in 1982 also indicated a fairly high abundance of larvae in the region. It is expected, therefore, that the stock will shift from the current low level to another expanding phase in the near future, being supported by the strong year-classes of 1980 and 82. However, if massive reductions in juvenile fish stocks are made by commercial fishing with non-selective gears such as purse-seine, stock abundance could decline still further.

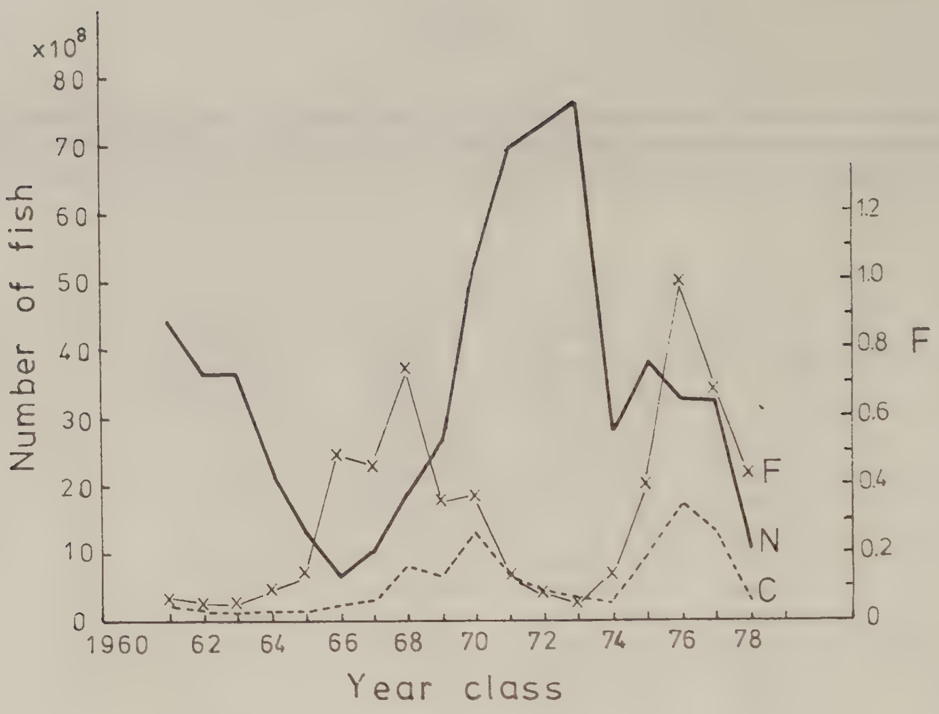

Figure 4

Change in the estimated stock number (N), commercial catch in number (C) and fishing mortality coefficient (F) at age-II of the common mackerel stock along the Pacific coast of Japan for the year-classes 1961-78. The natural mortality coefficient (M) was assumed to be 0.5 throughout the period (Watanabe, 1977, and supplement).

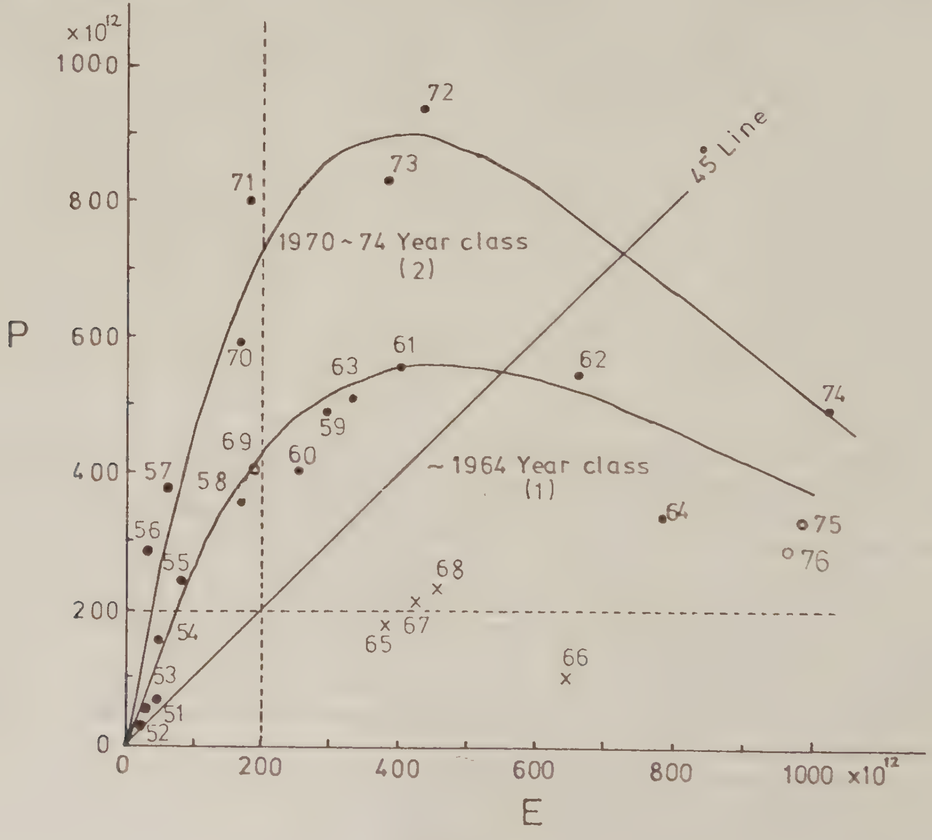

Figure 5

Reproductive relationship between the estimated total number of eggs spawned by the parental stock in each year (E) and that spawned by each of the broods during their adult stage, ages 3-5 (P) in the common mackerel stock along the Pacific coast of Japan. Numerals in the figure denote the year-classes (Watanabe 1977, and supplement).

## Table 4

Estimated number of eggs spawned by the parental stock in each year and those spawned by each of the broods during their adult stage (ages 3 to 5) of the common mackerel stock along the Pacific coast of Japan (Watanabe 1977, and supplement).

| Year (Year-Class) | Parental Spawning ($10^{12}$) | Brood's Spawning ($10^{12}$) | | | |
|---|---|---|---|---|---|
| | | 3 | 4 | 5 | Total |
| 1951 | 29 | 11.7 | 28.7 | 7.3 | 47.7 |
| 1952 | 29 | 14.5 | 9.7 | 7.0 | 31.2 |
| 1953 | 37 | 13.7 | 14.9 | 25.1 | 53.7 |
| 1954 | 48 | 43.1 | 45.5 | 72.2 | 160.8 |
| 1955 | 75 | 68.7 | 100.5 | 62.2 | 231.4 |
| 1956 | 34 | 62.1 | 91.1 | 116.4 | 269.6 |
| 1957 | 67 | 78.8 | 159.2 | 131.6 | 369.6 |
| 1958 | 151 | 73.7 | 196.7 | 60.4 | 330.8 |
| 1959 | 280 | 247.7 | 77.3 | 168.9 | 493.9 |
| 1960 | 247 | 96.7 | 237.7 | 66.3 | 400.7 |
| 1961 | 396 | 261.2 | 129.5 | 154.0 | 544.7 |
| 1962 | 645 | 163.9 | 231.6 | 113.5 | 509.0 |
| 1963 | 308 | 199.3 | 133.8 | 158.1 | 491.2 |
| 1964 | 782 | 118.1 | 145.0 | 69.9 | 333.0 |
| 1965 | 381 | 84.6 | 55.1 | 35.7 | 174.9 |
| 1966 | 647 | 26.6 | 40.2 | 35.2 | 102.0 |
| 1967 | 422 | 42.4 | 43.0 | 126.0 | 211.4 |
| 1968 | 459 | 57.8 | 110.2 | 64.3 | 232.3 |
| 1969 | 187 | 121.2 | 113.1 | 170.4 | 404.7 |
| 1970 | 163 | 127.9 | 275.8 | 186.4 | 590.1 |
| 1971 | 179 | 394.6 | 290.6 | 116.1 | 801.3 |
| 1972 | 432 | 430.6 | 356.6 | 146.4 | 933.6 |
| 1973 | 381 | 461.5 | 201.4 | 162.7 | 825.6 |
| 1974 | 1,024 | 155.4 | 244.2 | 92.8 | 492.4 |
| 1975 | 986 | 165.2 | 87.7 | 75.8 | 328.7 |
| 1976 | 962 | 71.2 | 119.8 | 87.2 | 278.2 |
| 1977 | 548 | 105.2 | 104.1 | - | - |
| 1978 | 616 | 44.6 | - | - | - |

### Japanese sardine

Japanese sardine along the Pacific coast comprises two stocks, the Pacific sub-population in the central and northern areas and the Ashizuri sub-population further south (Figure 6). It has been well known that the sardine stocks around Japan deforms their distribution pattern flexibly in accordance with the change in stock abundance and environmental conditions (Ito, 1961, Nakai, 1960, 1962, Watanabe, 1982).

The commercial catch from the Pacific sub-population, which had remained at an extremely low level during the 1950's with 10-20,000 tons of annual catch, further declined drastically in the mid-1960's after a temporary increase during 1961-62 up to 100-200,000 tons and reached its lowest levels in 1966 with only 3,000 tons catch (Figure 7 and Table 5). The catch, which showed a gradual recovery afterwards, increased again remarkably since 1973 and in 1977 reached 1 million tons. It has sustained a continuous increase thereafter and exceeded 2 million tons in 1981.

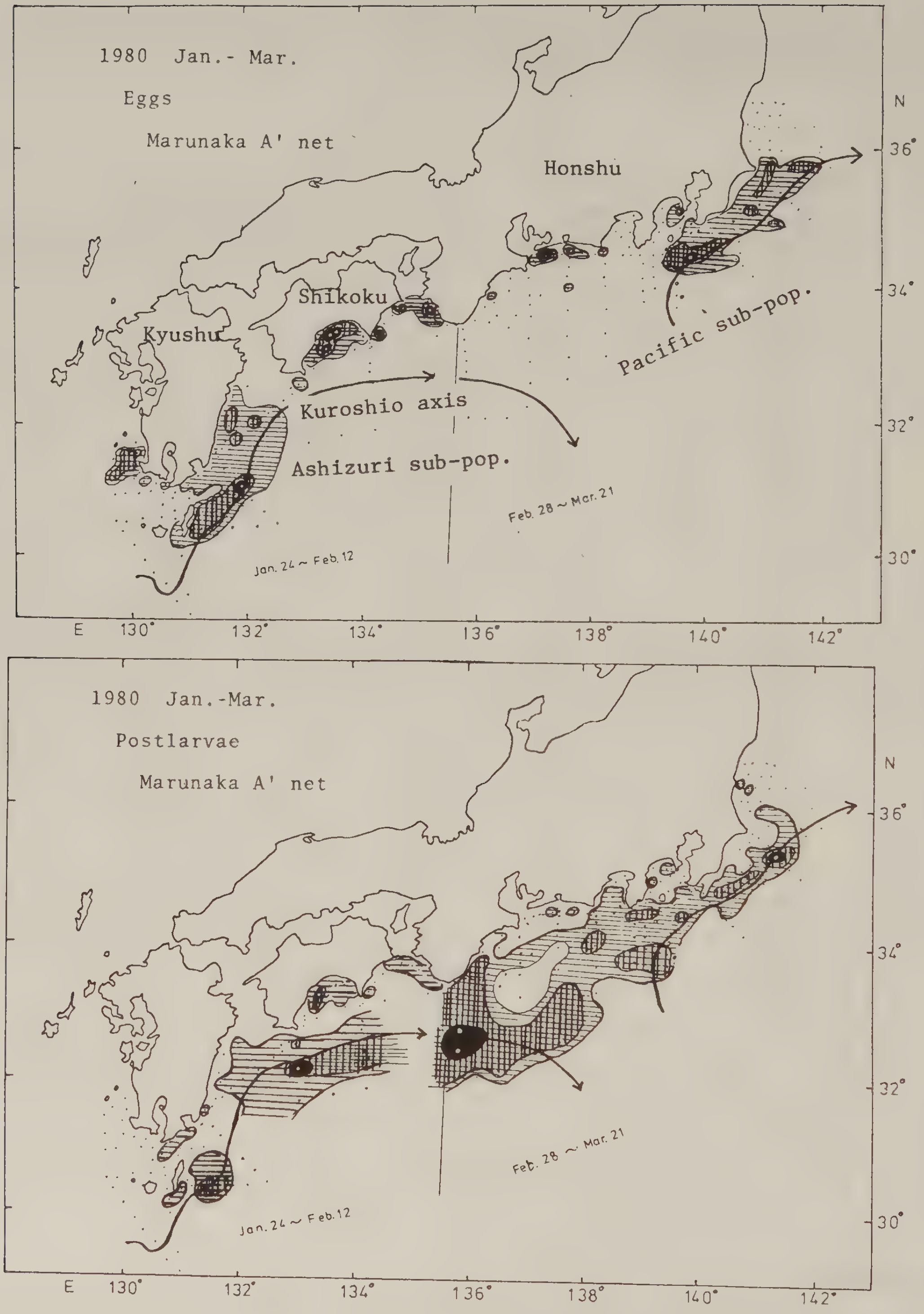
1980 Jan.- Mar.
Eggs
Marunaka A' net
Honshu
Shikoku
Kyushu
Kuroshio axis
Ashizuri sub-pop.
Pacific sub-pop.
Feb. 28 ~ Mar. 21
Jan. 24 ~ Feb. 12
N
36°
34°
32°
30°
E
130°
132°
134°
136°
138°
140°
142°
1980 Jan.-Mar.
Postlarvae
Marunaka A' net
Feb. 28 ~ Mar. 21
Jan. 24 ~ Feb. 12
N
36°
34°
32°
30°
E
130°
132°
134°
136°
138°
140°
142°

Figure 6

Spawning ground of the two major sub-populations, the "Pacific" and "Ashizuri", of Japanese sardine along the Pacific coast of Japan. Shadowed areas indicate the concentration of eggs and larvae collected by the 60 cm opening diameter plankton net by the R/V SOYO MARU during January to March 1980.

## Table 5

Annual change in the estimated total number of eggs spawned and the nominal catch of the Pacific sub-population of Japanese sardine during 1949-81. The change in the former in the Ashizuri sub-population is also given for 1977-81 (Nakai 1962, Watanabe et al., 1979 and supplement).

| Year | Pacific Sub-Population | | Ashizuri Sub-Population Eggs Spawned ($10^{12}$) |
|---|---|---|---|
| | Eggs Spawned ($10^{12}$) | Catch ($10^3$ tons) | |
| 1949 | 13 | N.A. | N.A. |
| 1950 | 18 | N.A. | N.A. |
| 1951 | 26 | N.A. | N.A. |
| 1952 | 19 | 21 | N.A. |
| 1953 | 12 | 22 | N.A. |
| 1954 | 22 | 13 | N.A. |
| 1955 | 22 | 10 | N.A. |
| 1956 | 22 | 18 | N.A. |
| 1957 | 26 | 20 | N.A. |
| 1958 | 11 | 18 | N.A. |
| 1959 | 10 | 18 | N.A. |
| 1960 | 45 | 19 | N.A. |
| 1961 | 221 | 101 | N.A. |
| 1962 | 96 | 97 | N.A. |
| 1963 | 14 | 44 | N.A. |
| 1964 | 14 | 7 | N.A. |
| 1965 | 17 | 5 | N.A. |
| 1966 | 4 | 3 | N.A. |
| 1967 | 5 | 6 | N.A. |
| 1968 | 2 | 17 | N.A. |
| 1969 | 4 | 17 | N.A. |
| 1970 | 1 | 15 | N.A. |
| 1971 | 2 | 48 | N.A. |
| 1972 | 17 | 39 | N.A. |
| 1973 | 22 | 234 | N.A. |
| 1974 | 153 | 243 | N.A. |
| 1975 | 210 | 409 | N.A. |
| 1976 | 271 | 677 | N.A. |
| 1977 | 318 | 1,110 | 17 |
| 1978 | 578 | 1,009 | 25 |
| 1979 | 248 | 1,097 | 61 |
| 1980 | 154 | 1,331 | 187 |
| 1981 | 148 | 2,060 | 358 |

NA: Data not available

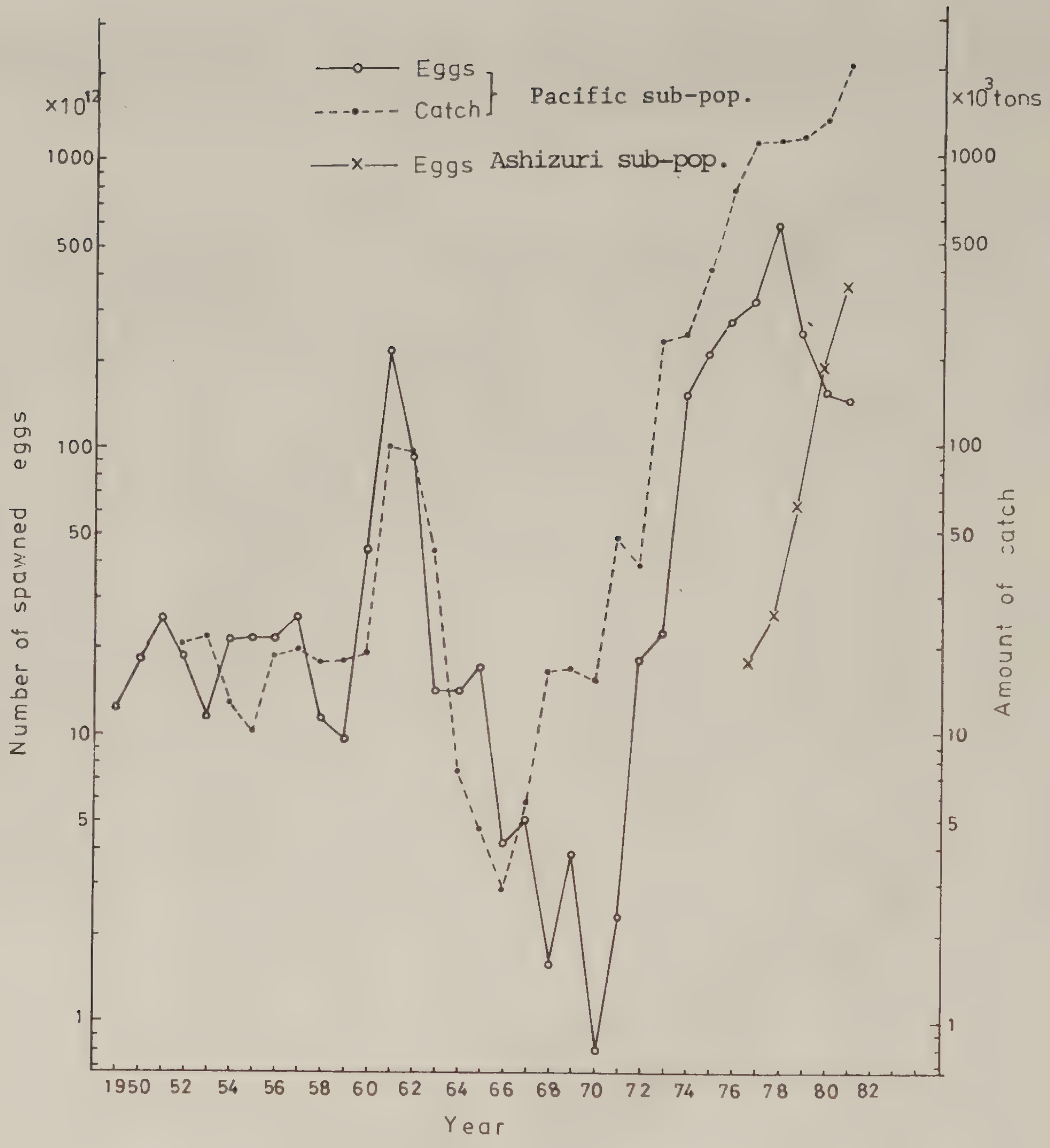

Figure 7

Annual change in the estimated total number of eggs spawned and the nominal catch of the Pacific sub-population of Japanese sardine during 1949-81. The change in the former in the Ashizuri sub-population is also shown for 1977-81 (Nakai 1962, Watanabe et al., 1979 and supplement).

The magnitude of spawning in the Pacific sub-population (Figure 7 and Table 5) shows that fluctuations resemble those of the commercial catches, that is, a low level (10-20 x $10^{12}$) until the mid-1960's with the exception of a temporary recovery during the early 1960's (200 x $10^{12}$ eggs) a drastic depression during the latter half of the 1960's reaching the lowest (1 x $10^{12}$ eggs) in 1970 and a rapid increase since 1973. It reached an extraordinarily high peak in 1978 at about 580 x $10^{12}$ eggs. These increases since 1973 resulted in the burst of the stock abundance during the mid to late 1970's and eventually in the prosperous catch by the commercial fishery as mentioned above. It decreased again thereafter but is still at a high level in recent years with about 150 x $10^{12}$ eggs estimated from the surveys.

The reproductive relationship of the Pacific sub-population shows a density-dependent pattern during the increasing period which fits the Ricker-type reproductive curve well (Figure 8 and Table 6). It shows a rapid increase in the broods' spawning since the 1972 year-class. Spawning by the 1974-76 year-classes increased greatly exceeding that of parental stock and formed a peak of the reproductive curve at about the 450 x $10^{12}$ egg level. The broods' spawning decreased substantially afterwards though the magnitude of parental spawning had remained at a very high level. The desirable spawning magnitude of the parental stock was estimated to be 150-250 x $10^{12}$, and the safety level to be 100 x $10^{12}$ where the spawning by a brood decreases precipitously against the further decline in the parental spawning.

The estimated annual allowable catches for a desirable level of spawning of the Pacific sub-population in recent years were high, at 2.03-2.23 million tons against the 1.01-2.06 million tons of annual commercial catch. The spawning survey carried out in 1982 indicated a lesser abundance of eggs and larvae in the central and northern areas of the region. This was, however, ascertained to be caused mostly by the delay in maturation of the extraordinarily strong year-class of 1980 (Figure 9 and Table 7), which did not mature at age-2 and subsequently did not spawn in 1982. It is quite likely, therefore, that the very large spawning will be made in 1983 when the abundant 1980 year-class joins in the spawning stock at age-3. The same phenomena were commonly observed when the stock was at an extremely high level during the 1930's (Nakai, 1962).

The spawning ground of the Ashizuri sub-population is located further south where the up-stream current of the Kuroshio flows (Figure 6). The spawning magnitude of the stock also increased markedly since 1978 and exceeded that of the Pacific sub-population in recent years reaching the highest in 1981 at about 360 x $10^{12}$ eggs (Figure 7 and Table 5). The combined spawning of the two sub-populations has therefore remained at a very high level even in recent years with 400-500 x $10^{12}$ eggs.

It is assumed that one of the major reasons for the burst in the spawning in the Ashizuri sub-population would be the substantial immigration of parental fish, especially the 1977 and 1978 year-classes from the Pacific sub-population which is presumed to have taken place during 1980-81 in connection with a change in environment, i.e. the disappearance of the meanders of the Kuroshio in the southwestern area of the region. This may explain, on the other hand, the sudden unusual decrease in the broods' spawning in the Pacific sub-population during 1977-78 (Figure 8), namely, due to emigration of spawners to the south. Another notable fact observed in the Ashizuri sub-population is that the spawning ground has been expanding, during the increasing period, further west down to 130°E where up-stream of the Kuroshio influence more on the transfer and dispersion of eggs and larvae to the north and east from its original area (132-135°E) (Figure 6). It is apparent, in these circumstances, that a substantial amount of the larvae of Ashizuri sub-population have been transferred and therefore recruited to the Pacific sub-population since the former had gained large abundance. It is also known that the intermingling of juvenile and adult fish has widely taken place between the two sub-populations after the expansion of the distribution range in each (Watanabe et al., 1979, Watanabe, 1982). This indicates that the sardine stock along the Pacific coast of Japan would have expanded its habitat to nearly its greatest range during the late 1970's.

The abundance of post-larvae in the entire region increased remarkably after 1977 (Figure 9 and Table 7). The 1980 year-class was, inter alia., strongest and mostly supported the massive catches along the Pacific coast of Japan during 1981-82 with more than 2 million tons of annual catch.

In summary, the Japanese sardine stock along the Pacific coast expanded its reproductive area and habitat during the bloom period and realized an extremely large abundance. The entire stock abundance and spawning magnitude are sustaining very high levels in recent years.

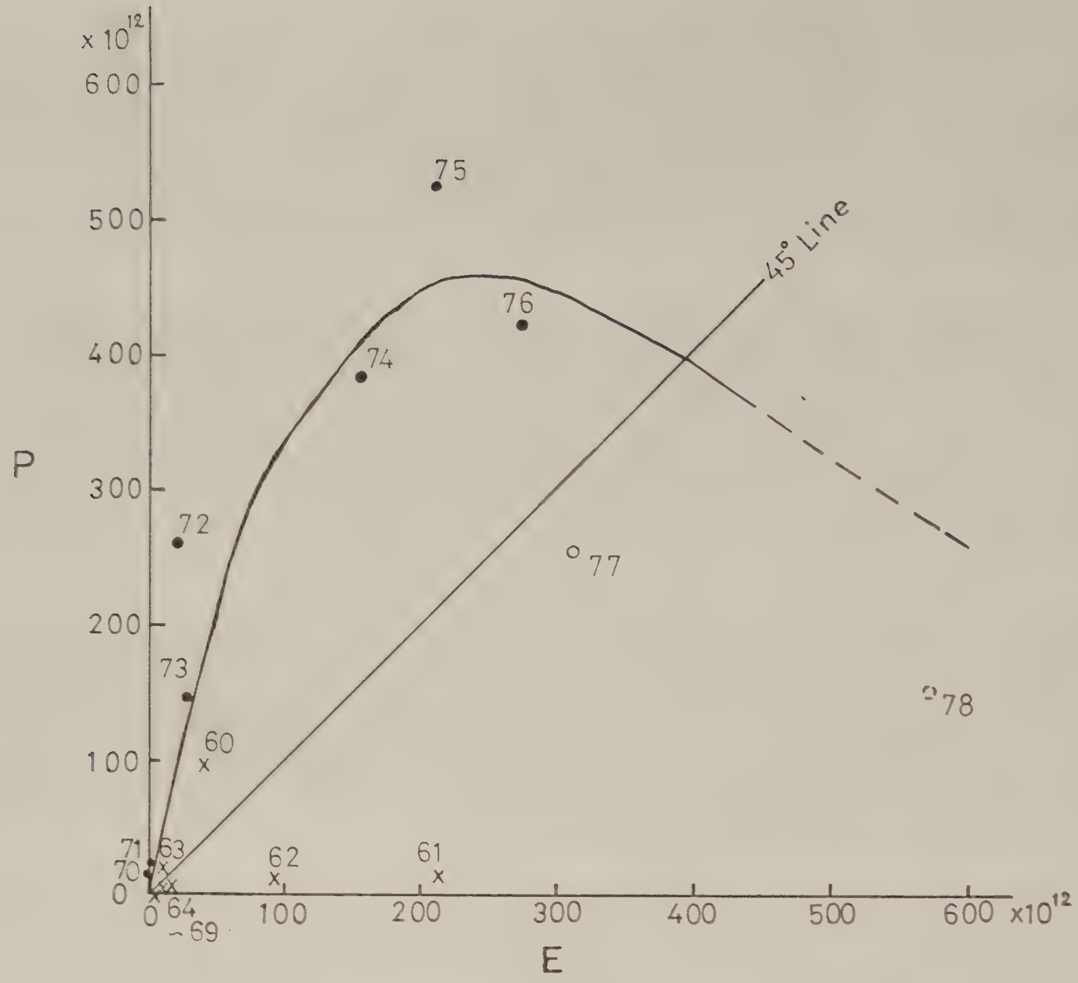

Figure 8

Reproductive relationship between the estimated total number of eggs spawned by the parental stock in each year (E) and that spawned by each of the broods during their adult stage, ages 2-4 (P), in the Pacific sub-population of Japanese sardine. Numerals in the figure denote the year-classes.

## DISCUSSIONS

### Common and species-specific natures in the mackerel and sardine stocks

The processes resulting in the changes in abundance appear to be quite analogous with each other and may have originated from the similarity of life history form and habitat of the two species. This suggests that these stocks have maintained an intrinsic potential burst even during the depressed period. The stocks could, therefore, readily begin to increase when the environment changes to more favourable conditions for early life history stages. For instance, the abundance of both common mackerel and sardine stocks both changed to increasing phases during the nearly same periods (early 1960's and early 1970's) and the spawning magnitude of both stocks showed a substantive decline during the same period (1969-71).

Table 6

Estimated number of eggs spawned by the parental stock in each year and those spawned by each of the broods during their adult stage (ages 2 to 4) of the Pacific sub-population of Japanese sardine.

| Year (Year-Class) | Parental Spawning ($10^{12}$) | Brood's Spawning ($10^{12}$) | | | |
|---|---|---|---|---|---|
| | | 2 | 3 | 4 | Total |
| 1960 | 45 | 96 | – | – | 96 |
| 1961 | 221 | 14 | – | – | 14 |
| 1962 | 96 | 14 | – | – | 14 |
| 1963 | 14 | 17 | – | – | 17 |
| 1964 | 14 | 4 | – | – | 4 |
| 1965 | 17 | 5 | – | – | 5 |
| 1966 | 4 | 2 | – | – | 2 |
| 1967 | 5 | 4 | – | – | 4 |
| 1968 | 2 | 1 | – | – | 1 |
| 1969 | 4 | 2 | – | – | 2 |
| 1970 | 1 | 17 | – | – | 17 |
| 1971 | 2 | 22 | – | – | 22 |
| 1972 | 17 | 153 | 98 | 10 | 261 |
| 1973 | 22 | 112 | 30 | 4 | 146 |
| 1974 | 153 | 232 | 103 | 48 | 383 |
| 1975 | 210 | 210 | 263 | 50 | 523 |
| 1976 | 271 | 267 | 101 | 56 | 424 |
| 1977 | 318 | 97 | 70 | 77 | 244 |
| 1978 | 578 | 27 | 63 | – | – |
| 1979 | 248 | 8 | – | – | – |

The Ricker-type reproductive relationship was also assumed in both the stocks. That is, the spawning by broods increases markedly exceeding that of parental stock during the expanding period, which results in a rapid increase in the entire stock abundance. However, the broods' spawning reduces its increasing pace in accordance with the increase in the entire stock abundance and finally becomes substantially lower than that of the parental stock once the entire stock abundance has reached an extraordinarily high level. If such a serious decrease in recruitment continues for a few years and if unfavourable environmental conditions surround the stock, the entire stock abundance would drastically decline, which may however enable the stock to shift in a growing phase some time in the future. (See discussion by Sharp, Csirke and Garcia this Volume).

On the other hand, a negative density-dependent effect on any reproductive relationship may arise when the entire stock has expanded its habitat to its widest possible extent at an extremely high level of abundance. That is, there is an apparent physical/qualitative decline in parental fish, such as delays in growth and maturity, decreases in fecundity, and deterioration in the nutrient condition of eggs etc. (Nakai, 1962, Watanabe, 1970, 1982), may inevitably follow which might result in fewer and lower viability of eggs and larvae, and eventually in serious decreases in recruitment. The stock could and will drastically decline again if unfavourable environmental conditions surround the stock under such conditions. In fact, the delay in growth and qualitative deterioration in maturity were observed in the common mackerel stock during the late 1970's and the delay in growth and maturity in the 1980 year-class of Japanese sardine.

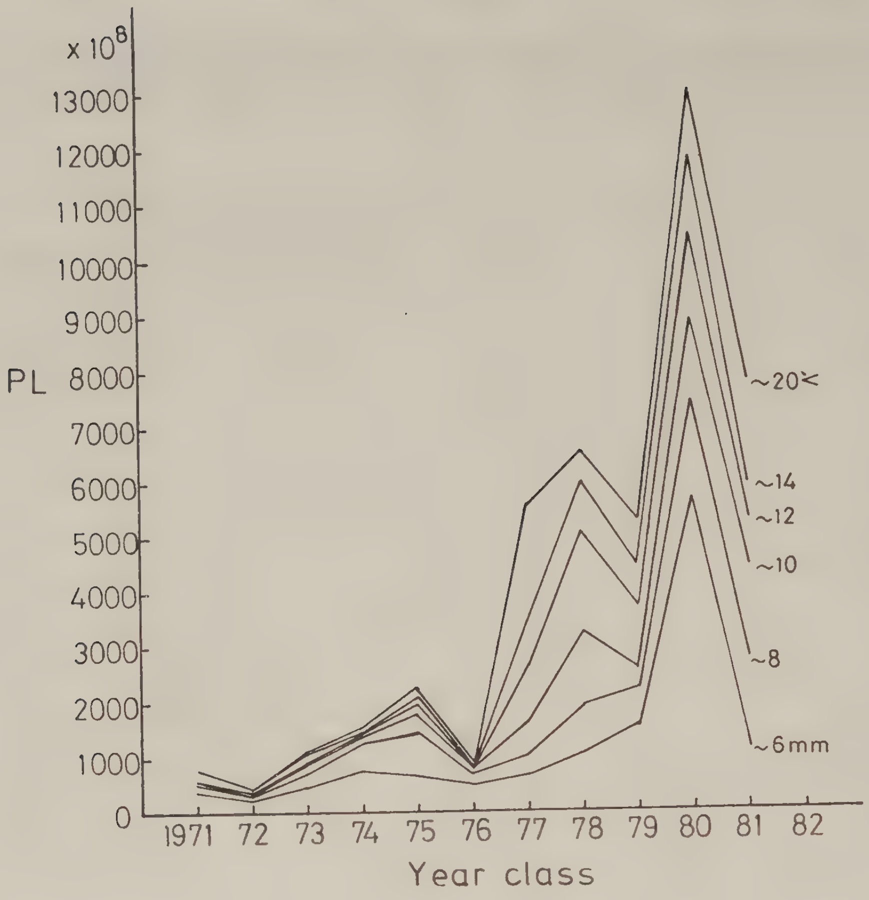

Figure 9

Change in the estimated abundance of the post-larva in index (PL) by body-size-group of the Japanese sardine stock along the Pacific coast of Japan for the year-classes 1971-81. The indices for the 8 mm size-group and above are shown with the accumulated values including those of all the smaller groups. The larvae were collected by perpendicular tows with a 60 cm opening diameter plankton net by the R/V SOYO MARU during January to April every year.

One specific nature observed in the sardine stock was the expansion of spawning and nursery grounds to the up-stream area of the Kuroshio. This may have enabled the stock to greatly expand its habitat and migratory areas to realize eventually an extraordinarily large biomass exceeding the prior spatial limiting factors imposed on the original single population level. Such a structural deformation has not been clearly observed in the mackerel stock. However, it may be consistent for both species that the stocks have expanded their habitat to the widest possible distribution within the limiting factors of each species in the region during the prosperity period.

The three phases are assumed to be employed in the expanding process of the sardine stock, namely, (1) recycling of the stock is being made at sub-population (or race) levels and no intermingling occurs among each unit, (2) the spawning grounds are substantially expanded in accordance with the increase in the stock abundance in each of the sub-populations and the immigration from one to the other or the intermingling takes place to some extent and (3) further expansion of spawning/nursery grounds are made, accompanied by the enlargement of habitat along with the extraordinarily large abundance, and a large migratory area is formed by juvenile and adult fish extending beyond the prior ranges of each sub-population (Nakai, 1961, 1962). The prosperity stage is realized at phase-3 but the stock may have been over-populated at the same time (Watanabe, 1982). The current status of the Japanese sardine along the Pacific coast is considered to be the late-2 or early-3 stage of the above-mentioned phases.

Table 7

Change in the estimated abundance of the post-larvae in index by body-size-group of the Japanese sardine stock along the Pacific coast of Japan for the year-classes 1971-81. The larvae were collected by perpendicular tows with a 60 cm opening diameter plankton-net by the R/V SOYA MARU during January to April every year.

(Number of larvae in index)

| Year-Class (Year) | Body Size (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | -6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-20 | 20- | Total |
| 1971 | 392 | 129 | 60 | 0 | 0 | 155 | 50 | 786 |
| 1972 | 232 | 63 | 24 | 30 | 56 | 50 | 10 | 465 |
| 1973 | 493 | 220 | 156 | 91 | 52 | 77 | 21 | 1,110 |
| 1974 | 764 | 497 | 120 | 39 | 41 | 85 | - | 1,546 |
| 1975 | 671 | 787 | 319 | 153 | 165 | 107 | 21 | 2,223 |
| 1976 | 503 | 196 | 75 | 44 | 40 | 36 | 7 | 901 |
| 1977 | 666 | 358 | 622 | 984 | 808 | 1,671 | 381 | 5,490 |
| 1978 | 1,043 | 860 | 1,359 | 1,766 | 914 | 498 | 35 | 6,475 |
| 1979 | 1,559 | 666 | 349 | 997 | 846 | 730 | 99 | 5,246 |
| 1980 | 5,638 | 1,751 | 1,450 | 1,461 | 1,420 | 1,100 | 109 | 12,929 |
| 1981 | 1,158 | 1,586 | 1,687 | 804 | 663 | 854 | 1,015 | 7,767 |

It should also be noted here the important role of dynamic changes in the Kuroshio flow in the change of the sardine stock, especially the role of the large meanders in the southwestern area of the region. In fact, the strongest year-class of sardine appeared in 1980 when a large meandering of the Kuroshio temporarily disappeared. It is also reported that some changes in the meanders would have often boosted the burst of feed organisms for larvae in the area. The Kuroshio has, thus, played a very important role in both physical (transfer and dispersion of eggs and larvae) and nutritional (feed organisms) conditions of the sardine stock.

It is concluded that the common mackerel and Japanese sardine stocks along the Pacific coast of Japan require similar environmental conditions for their prosperity and that although the favourable and unfavourable conditions are formed alternatively, with several years time interval for each sequence, the species-specific dynamics of the several stocks abundances are independent of the physical and quantitative status of each other stock.

## Management strategy

It is probable that commercial fishing could nip in the bud potential increases in abundance of a depleted stock if a significant stock reduction is made when the stock begins to recover. However, the magnitude of the potential and the pace of the recovery of mackerel and sardine stocks appear to be larger and fast enough to overcome the ordinary reduction by commercial fishing. It is also unlikely that fishermen would impose intensive fishing on mackerel and sardine when the stocks are at a low level.

It is apparent, from the analyses made in this paper, that once the stocks have started growing, the increases in the abundance greatly exceeds the fishing mortality, even if the reduction is massive. The effect by fishing on these stocks is therefore not so significant so long as the reduction remains within the range which corresponds with the stock size. It becomes seriously significant only when the stocks are in a declining phase, these being accompanied by lesser recruitment. Fishing should be limited on such occasions within the allowable catches which correspond with their minimum or safety level of spawning magnitude (200 x $10^{12}$ eggs for common mackerel and 100 x $10^{12}$ eggs for the Pacific sub-population of Japanese sardine) firstly to prevent any further deterioration of the stock and secondly to ensure the stock to shift soon in the growing phase.

## FUTURE STUDIES

Stock assessment by spawning survey, although still involving several problems to be overcome in the future, is one of the most effective ways to assess dynamic changes in stock abundance from the reproductive sector of fish, specifically for neritic pelagic fish resources as the author has described in this paper. In addition to technical improvement of the survey methods, tools, handling of samples and data processing, the following studies have been identified as needing to be carried out intensively in the future, as the improvement of the accuracy on the estimate of annual recruitment is, inter alia, essential for the better assessment of these resources.

(1) Observation on and evaluation of the physical quality of adult fish as spawners with suitable measures and the analysis of the time-series data on the change in fecundity and the number of eggs really spawned by adult fish in conjunction with the changes in abundance/density of the stock and environment.

(2) Clarification of the mechanisms and their roles in mortality during the early stage of life.

(3) Observation on and analysis of the changes in distribution pattern and the structure of the stock in connection with the changes in environment, abundance of the stock and inter-species relationships with the other neritic pelagic fish stocks.

(4) Examination of the catch data and data collection system to obtain a better estimate (unbiassed) of age-compositon of the stock.

(5) Comparative studies with the results obtained by the other methods and among the other species in conjunction with the clarification of the common and species-specific natures.

The author believes that the above-mentioned studies would greatly encourage the progress in the studies in each species and would improve also the global understanding on the dynamics of neritic pelagic resources including jack mackerel, saury, herring, anchovy, Japanese flying squid etc. at the community level.

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*YELLOW AND CHINA SEAS - MAR AMARILLO Y MAR DE LA CHINA*

# ON THE FISHERIES OF SPANISH MACKEREL (*Scomberomorus niphonius*) IN THE YELLOW SEA AND POHAI SEA

by

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## SUMMARY

The Spanish mackerel, *Scomberomorus niphonius* in the Yellow Sea and Pohai Sea is a pelagic fish having long distant migrations. Its fisheries have a long history and chiefly operated with drift nets. This article dealt with the migration, age, growth, mortalities, population dynamics and fisheries management of *S. niphonius* and reviewed works by other authors.

Age composition of the spawning population in the spring fishing season comprised 6 ages. This observation is somewhat different from the works of other authors, but it makes no difference to the study of population dynamics because of the small numbers of the older fish. Sexual maturity in male fish begins at age 1, and the females mature at age 2. These fish are recruited very young and the majority of fish in the spawning population are young recruits. Their abundance plays an important role in population dynamics.

The survival rate of *S. niphonius* (0.09) is much smaller than that of *S. cavalla* (0.52). The average total mortality coefficient is 2.4123, natural mortality coefficient being 0.2566, fishing mortality coefficient being 2.1557. Therefore, even if the fishing effort increases, the catch will not increase correspondingly. The catch from the spawning population in spring fishing season varies in the range of 10,000-30,000 tons.

Some measures for fisheries management are suggested on the basis of the above information, which are chiefly the strict prohibition of trawling the fish below 450 mm in length and limitation of fishing effort.

The present production is situated at a growth over-fishing phase. Hence, it seems that these measures could only be put into practice with some difficulty.

*YELLOW AND CHINA SEAS - MAR AMARILLO Y MAR DE LA CHINA*

# THE HERRING (*Clupea harengus pallasi*) AND ITS FISHERIES IN THE YELLOW SEA

by

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## Resumen

En este trabajo se discute la distribución, crecimiento, mortalidad y relación stock-reclutamiento del arenque del Mar Amarillo, y se trata de establecer una estrategia para la ordenación de sus pesquerías. Los resultados obtenidos se resumen a continuación:

Se cree que el arenque que se encuentra durante todo el año en las áreas al norte de los 34°N del Mar Amarillo pertenece a una raza del arenque del Pacífico tradicionalmente conocido como arenque del Mar Amarillo.

El patrón de crecimiento del arenque del Mar Amarillo puede ser descrito tanto por la ecuación de von Bertalanffy, como por la ecuación de Brody Robertson. La abundancia de individuos de edad 1 de las clases anuales de los años 1966 a 1974 fue estimada por el método de Pope, el coeficiente de mortalidad total para cada clase anual a sus distintas edades fue cálculado por el método iterativo.

El reclutamiento del arenque del Mar Amarillo ha mostrado fluctuaciones considerables desde 1966. De la abundancia de individuos de edad 1 de nueve clases anuales sucesivas entre 1966 y 1974 obtenidas por el análisis de cohortes se observa que la abundancia en la clase anual de 1970 es la más abundante, y que la clase anual de 1970 fue 53 veces más grande que la de 1969. No se ha observado ninguna correlación significativa entre los adultos y el reclutamiento, y se asume que el reclutamiento del arenque del Mar Amarillo es afectado fuertemente por los factores ambientales. En 1972 un fuerte viento del sur "Typhoon Nº 3" impactó seriamente la sobrevivencia de juveniles.

De los resultados obtenidos de la aplicación de un modelo de rendimiento por recluta (Y/R), y considerando los beneficios económicos (los ovarios de arenque maduros tienen un valor bastante alto) se sugiere una estrategia de manejo donde la longitud estándar mínima en las capturas sea de 230 mm., lo que equivale a individuos de 2 años de edad. Además se sugiere que se prohiba a los arrastreros operar desde el invierno hasta la época de desove siguiente. Cuando estas estrategias sean adoptadas, la mortalidad por pesca debe disminuir ligeramente y el stock adulto debe aumentar, pero posiblemente no haya un aumento significativo del tamaño total del stock. Los rendimientos de arenque por parte de los arrastreros disminuirán, pero esto será compensado por un aumento de rendimiento por parte de la pesca que se realiza más cerca a la costa, esto reducirá el consumo de energía. La producción de ovarios de arenque maduro y los beneficios económicos de la pesquería de arenque en general deben aumentar en forma apreciable.

# INTRODUCTION

According to the memories of the old fishermen and historical background information, Yellow Sea herring have had two recorded peaks of catch in the years of 1900 and 1938. Catches appeared again in small amounts in the landings of trawlers in 1966 and 1967. In 1969 they began to increase gradually with a catch of 4,200 tons, 14,000 tons in 1970 and catches reached the highest level at 174,000 tons in 1972. Then the following catches decreased. Now the catch fluctuates at a low level around 20,000 tons. Papers on Yellow Sea herring published in China are listed in the References at the end of the paper. The information and results of investigation relating to the biology, dynamics of the population, etc. of Yellow Sea herring during the peak at the third time are reported in this paper.

## Aspects of the fisheries

At the beginning of the 1970's, Yellow Sea herring were one of the more important fisheries in the Yellow Sea. Then the fisheries were composed of two parts, one offshore segment and an inshore segment. The former included trawlers, which operated nearly all year round, and purse seines, which operated in winter fishing season to catch wintering populations. The latter included various settled-nets and small purse seiners, which operated in a small area and chiefly caught pre-spawning herring. The ratio of production between these two components was about 1:1.

The variation of the fishery production is shown in Figure 1. The catch has been fluctuating at a low level of around 20,000 tons since 1976. As a result of the decrease of stock size and limitation on trawlers fishing Yellow Sea herring, this fishery has as yet nearly only operated settled-nets during the spring fishing season. The fishery exhibited large variations in a very short period and the accumulation of data, standardization of fishing effort, etc., has been difficult.

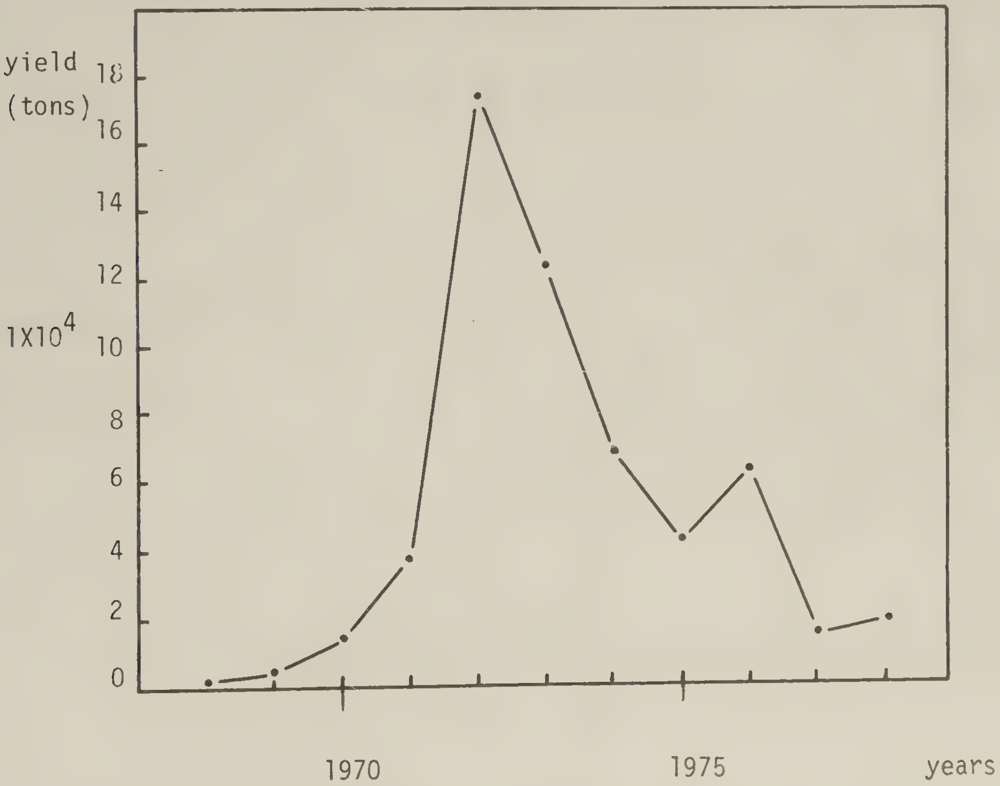

Fig. 1. Yellow Sea herring, the curve of variation in yield

## POPULATION AND DISTRIBUTION

### Distribution

During March each year herring are distributed in the shallow waters along the coasts of Shandong peninsula and southeastern part of Liaodong peninsula for their spawning activities. The main spawning grounds are situated in the inshore areas from Shidao to Waihai, Shangdong Province. The area of the spawning grounds is correlated with the population abundance. The water temperature of spawning varies over 1° to 5°C. The first maturation is at age two. Eggs are demersal, and adhere to the sea weeds and other fixed objects. After spawning, the adults move to the deeps and scatter to search for food. In summer they are chiefly distributed in the middle and north parts of the Yellow Sea (34°-39°N, 123°-125°E), and feed in the 60-80 meters in depth areas. In autumn and winter, the area where they are distributed is smaller, and chiefly include the middle part of the Yellow Sea (35°-37°N, 123°30'-125°E), where the water is 70-80 meters in depth. In late winter and early spring (February) the individuals begin to move northwards in groups (by lengths) in spawning migrations. The distribution of immature juveniles is different from that of adults, generally they (at age 1) are distributed a little more northwards, and the adults (at age 2 and above) a little more southwards.

### Population

Ye, et al. (1981) have compared Yellow Sea herring to the races of Hokkaido, Japan and Korea employing six main countable features. By statistical tests it is shown that the Yellow Sea herring differ significantly from the other two races in these main countable features. Further, according to exploratory fishing results of twenty-eight surveys from 1971-1978 and more than one thousand fishing records from the industrial fisheries, we have never discovered Yellow Sea herring south of 34°N. Hence we suggested that Yellow Sea herring inhabiting the Yellow Sea north of 34°N all year round is a unique population of Pacific herring, called Yellow Sea herring.

## GROWTH PATTERN AND MORTALITY

### Growth

The growth curves of Yellow Sea herring are drawn from observed data in Figures 2 and 3. The common growth pattern can be described by a von Bertalanffy growth equation, in which the parameters are: $W_\infty$=314g., $L_\infty$=308mm, K=0.59, $t_o$=-0.54. The inflection of the growth curve in weight is situated at t=1.3 years and $W_{1.3}$=91.2g., which is equivalent to 0.290W . Equations (1) or (2) are used to show growth rates. The differences between equations (1) and (2) are that, the growth rate is defined by t in equation (1) as:

$$\frac{dw}{dt}=3KW_\infty e-K(t-t_o)(1-e^{-K}(t-t_o)^2 \text{---}(1)$$

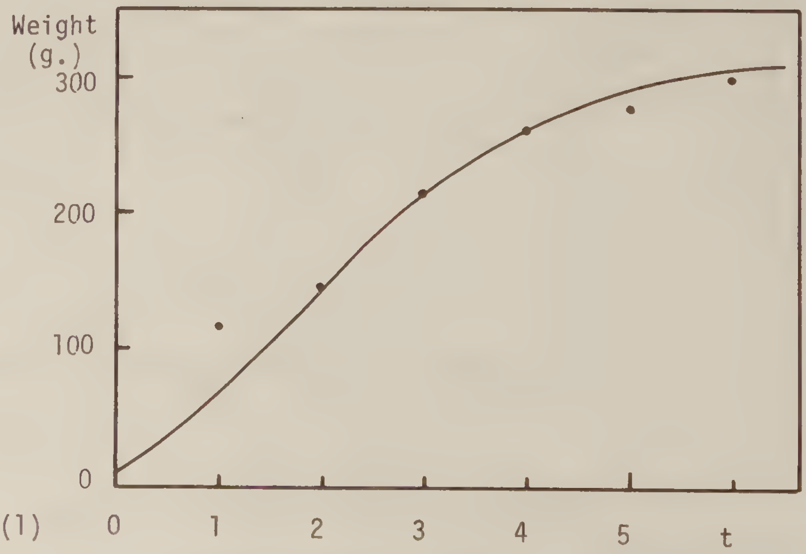

Fig. 2. Yellow Sea herring, the curve of growth in weight

while in equation (2) it is defined from observed weights as:

$$\frac{dw}{dt}=3K(W_{\infty}^{1/3}W_t^{2/3}-W_t)\text{-------}(2)$$

Figure 4 shows the growth rate in weight.

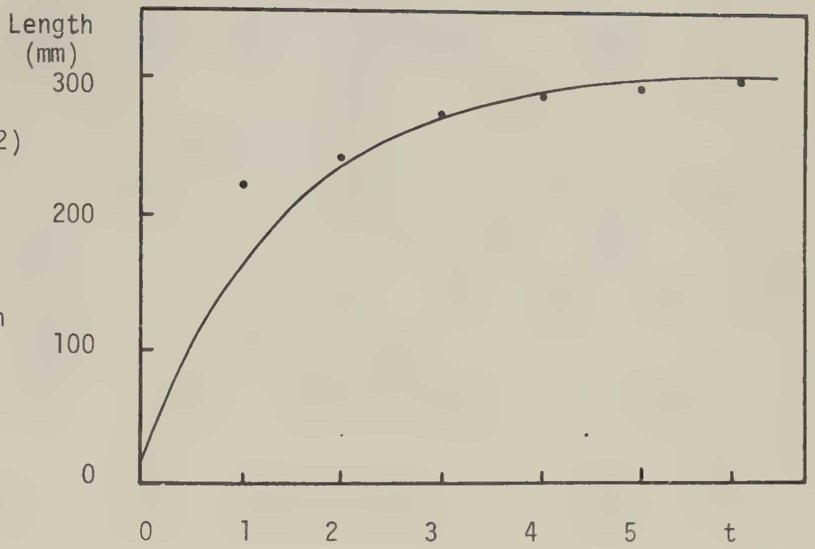

Fig. 3. Yellow Sea herring, the curve of growth in length

In addition, another growth equation also used to fit the data of Yellow Sea herring is shown in Table 1. The fitting of Robertson's equation is better than that of Brody or von Bertalanffy's equation. The sum of square of residual error of Robertson's equation is smaller than that of von Bertalanffy's, the main reason is that von Bertalanffy's equation does not reflect well the growth of juveniles.

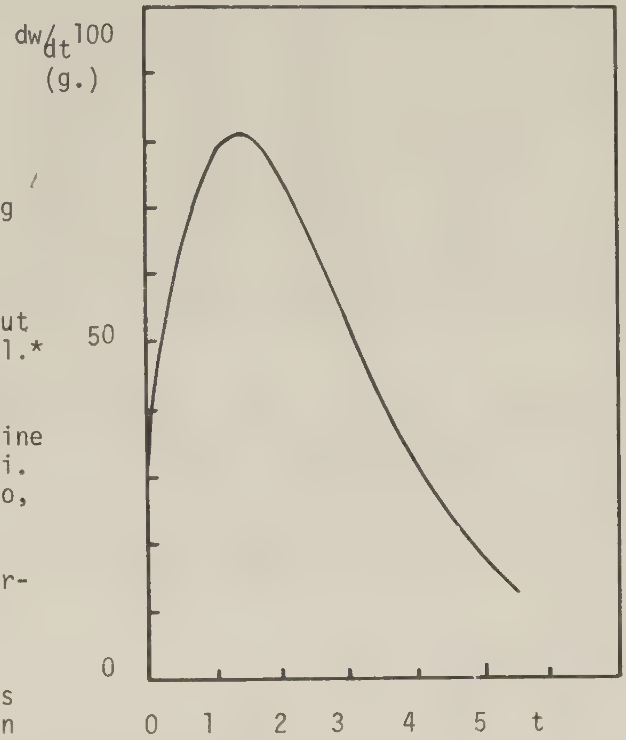

Fig. 4. Yellow Sea herring, the curve of growth rate

## Mortality

The coefficient of natural mortality for Yellow Sea herring estimated from conventional methods by Ye et al.(1981) is about 0.11, but appears not to be reliable. Gulland pointed out that the value is somewhat small.* In 1980, it was estimated to be about 0.2 by K. Brander during FAO/UNDP Training Course on Marine Resources Evaluation in Bhanghai. Zhang** (1981) used 0.2 also. So, I also use the value 0.2 as the natural mortality coefficient. The abundances of 1966-1974 year-classes at age 1 from estimates using Pope's method (1972) and also the fishing mortality coefficients for each year-class of various ages are tabulated in Table 3. Table 2 is the yield of year-classes of Yellow Sea herring in successive years at various ages. In addition, catch per unit of effort of 1970 year-class in 1972 and 1973 was used to estimate the total mortality coefficient, which is about 1.05 (Ye, et al. 1981). When the natural mortality coefficient is subtracted from total mortality, the fishing mortality coefficient is found to be about 0.85, which approximates the value of 0.817 in Table 3.

* personal communication with John A. Gulland in 1981.

** Zhang Yu-Xi, 1981. The present situation of Yellow Sea herring population and its rational exploitation. (unpublished, China.)

Table 1. Comparison of various growth equations

| author | expression | r | F-test |
|---|---|---|---|
| Brody | $W_t=W -Be^{-Kt}$ | 0.928 | ** |
| Robertson | $W_t=W /(1+ec-bt)$ | 0.985 | ** |
| V. Bertalanffy | $W_t=W (1-e^{-K}(t-t_o))$ | 0.937 | ** |

Table 2. Yield of Yellow Sea herring in successive years (unit x$10^6$ ind.)

| year-classes | ages | | | | | | total |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| 1966 | 27.51 | 6.20 | 10.18 | 28.56 | 23.11 | 10.97 | 106.53 |
| 1967 | 11.20 | 5.09 | 14.28 | 15.54 | 6.09 | 2.51 | 54.71 |
| 1968 | 28.40 | 19.24 | 53.40 | 25.59 | 4.90 | 1.19 | 132.72 |
| 1969 | 20.89 | 6.97 | 4.88 | 5.38 | 0.82 | (0.30) | 39.24 |
| 1970 | 364.89 | 1064.50 | 562.52 | 80.13 | 2.34 | 0.30 | 2074.68 |
| 1971 | 12.76 | 47.58 | 23.79 | 2.22 | 0.43 | (0.20) | 86.78 |
| 1972 | 131.90 | 291.60 | 31.05 | 6.26 | 0.52 | 0.32 | 461.65 |
| 1973 | 69.09 | 38.70 | 25.74 | 1.17 | 0.38 | 0.11 | 135.19 |
| 1974 | 440.15 | 441.90 | 44.24 | 6.40 | 0.60 | (0.20) | 923.29 |

Table 3. Fishing Mortality coefficient of Yellow Sea herring at various ages in successive years

| *** \ ** | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | average |
|---|---|---|---|---|---|---|---|---|---|---|
| 1967 | 0.139 | | | | | | | | | 0.139 |
| 1968 | 0.042 | 0.136 | | | | | | | | 0.089 |
| 1969 | 0.090 | 0.084 | 0.158 | | | | | | | 0.111 |
| 1970 | 0.389 | 0.355 | 0.153 | 0.533 | | | | | | 0.357 |
| 1971 | 0.630 | 0.892 | 0.808 | 0.340 | 0.147 | | | | | 0.563 |
| 1972 | 0.710 | 0.957 | 1.280 | 0.424 | 0.817 | 0.120 | | | | 0.718 |
| 1973 | | 1.603 | 0.944 | 1.209 | 1.640 | 0.853 | 0.272 | | | 1.087 |
| 1974 | | | 0.632 | 0.583 | 1.297 | 1.673 | 1.760 | 0.565 | | 1.085 |
| 1975 | | | | * | 0.100 | 0.694 | 1.000 | 0.730 | 0.529 | 0.611 |
| 1976 | | | | | 0.017 | 0.272 | 0.558 | 1.945 | 1.824 | 0.923 |
| 1977 | | | | | | * | 0.697 | 0.416 | 0.953 | 0.483 |
| 1978 | | | | | | | 0.642 | 0.230 | 0.354 | 0.409 |

* absent<br>
** year-classes<br>
*** fishing years

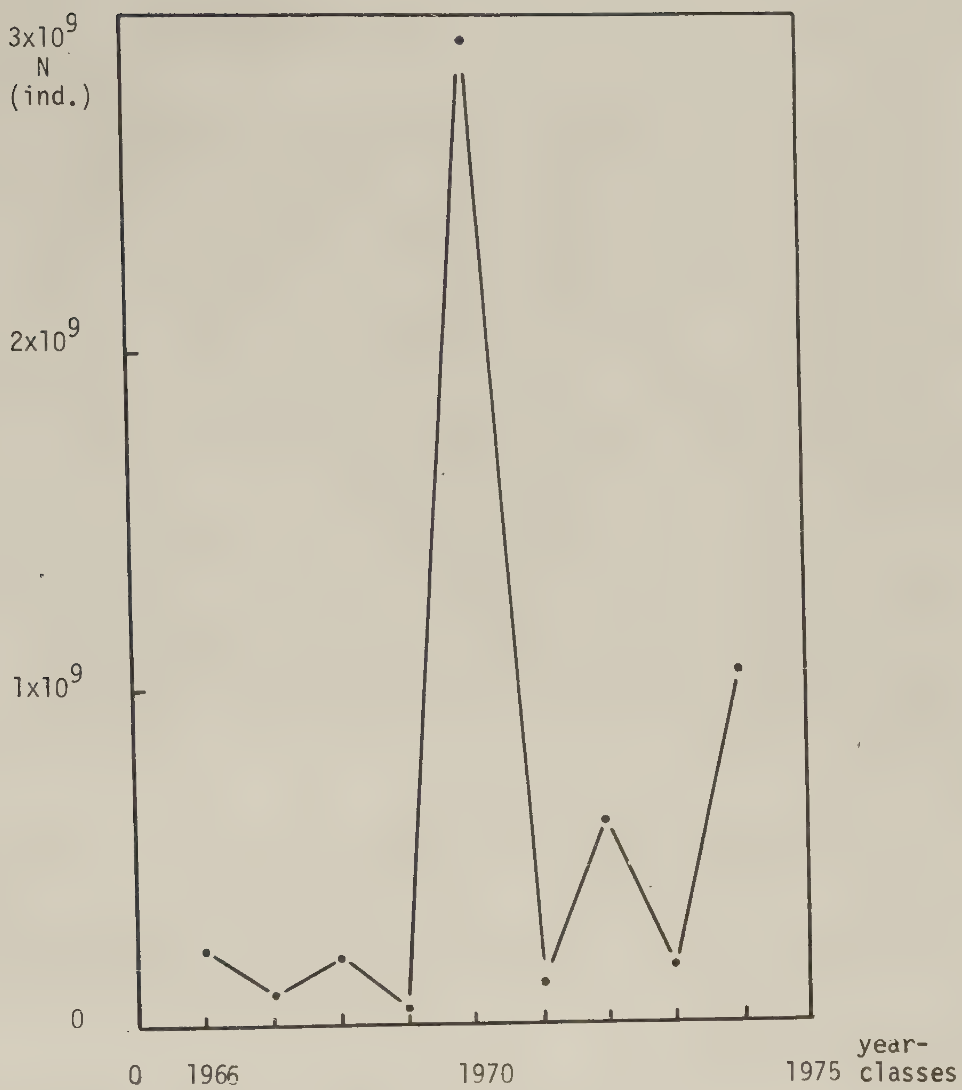

Fig. 5.

Yellow Sea herring, the curve of variation in abundance of year-classes

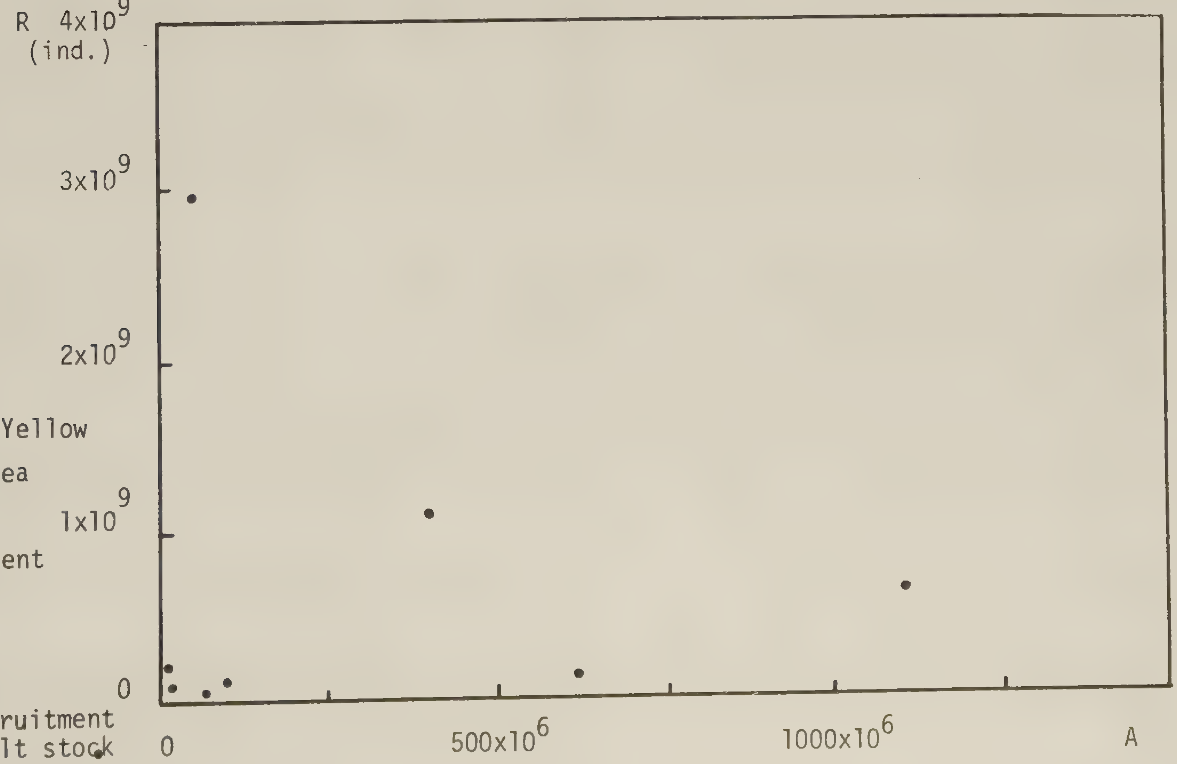

Fig. 6. Yellow

Yellow Sea herring, stock-recruitment relation

R = Recruitment
A = Adult stock

## POPULATION DYNAMICS

The recruitment of Yellow Sea herring shows considerable variations from year to year. Figure 5 is drawn with stock size of nine year-classes (1966-1974) at age 1 estimated with cohort analysis. The abundance of the 1970 year-class is the greatest with about $2940 \times 10^6$ individuals, and $2074 \times 10^6$ individuals caught in total during the fishable life-span (6 years in 1971-1976), whereas the 1969 year-class is the smallest with about $55 \times 10^6$ individuals and $39 \times 10^6$ individuals caught over 6 years (1970-1975). These two year-classes differ by 53 times in stock size and yield. What we are concerned about is how to decide which factor makes the greatest impact on the stock size of Yellow Sea herring, the impact of adult stock on recruitment, or the impact of fishing on recruitment. Figure 6 is drawn to indicate the relation between adult stock and recruitment, in which the recruitment is represented by the number of each year-class at age 1 estimated by cohort analysis, and the yield of the mature individuals was taken as the index of abundance of the adult stock. As a result of short time series, when the data in the Figure 6 are tested statistically the result shows no correlation. It appears that the adult stock of Yellow Sea herring has little impact on its recruitment, or in other words, that fishing has little impact on the recruitment, which is therefore chiefly effected by environment. We have seen for the Yellow Sea herring that strong southward wind has a serious impact on the survival of the juveniles. In 1972, there was a great number of adults, eggs and larvae, but in the last ten-day period of July in that year, there was a typhoon (No. 3) over the northern Yellow Sea along Shandong and Liaoning Province. The wind was southeastward with wind forces of 8-9 on the Beaufort wind scale. As a consequence, few of the 1972 year-class individuals survived.

The main pelagic fish populations exploited in the Yellow Sea and Pohai Sea are Yellow Sea herring, spanish mackerel, common mackerel and pomfret (*Stromateoides argenteus*), in which the pomfret population is more stable, the catches of Yellow Sea herring has fluctuated around a low level of 10,000-20,000 tons per year in recent years. The common mackerel which migrates into the Yellow Sea also has decreased somewhat, but interspecific changes have not appeared yet, while this phenomenon is more obvious in demersal fish.

### Yield per recruit

Equation 3 is used to examine the impacts of fishing pattern on the yield of Yellow Sea herring,

$$y/_R = \sum_{t=t_r}^{t} \frac{(1-e^{-Z_t})}{Z_t} F_t W_t e \text{ --------}(3)$$

where t and $t_r$ indicate the maximum and recruited ages, respectively. According to age compositions in 1970-1979, because fish above age 6 contribute about only 0.2%, and age 6 0.4%, age 6 is taken as the maximum age. Other parameters were introduced in above sections. Figure 7 is a curve of constant yield per recruit with recruitment at age 2, being a flat-topped yield curve and having a maximum value of y/R at about F=1.0. Figure 8 describes yield per recruit as a function of mean selection age i.e. recruited age, with F=1.0. The maximum of the curve occurs at about t=3. The adjustment of mesh size has more potential for increasing production than that of adjusting F.

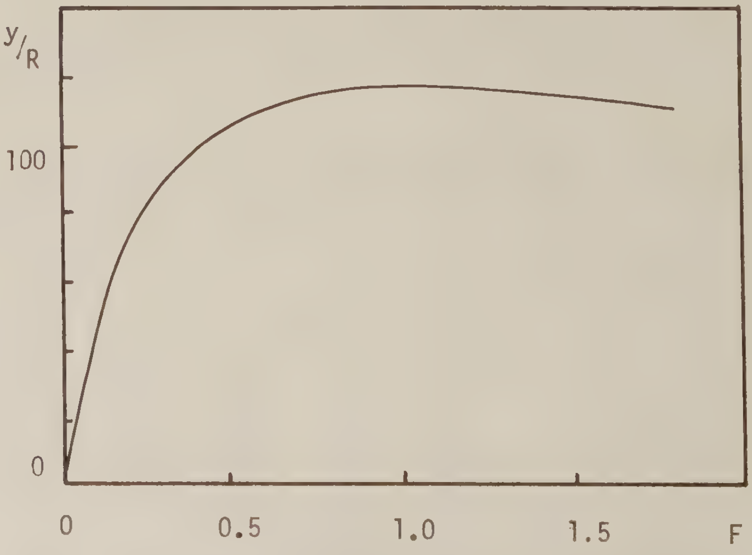

Fig. 7. Yellow Sea herring, yield against fishing mortality with t=2.0

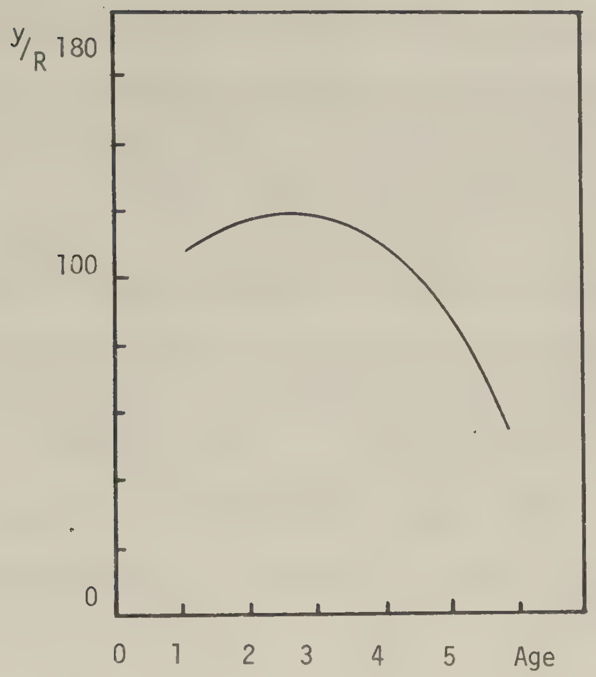

Fig. 8. Yellow Sea herring, yield against mesh with F=1.0

## MANAGEMENT STRATEGY

The management strategy should be related to management objectives and this presents complex problems. Gulland (1977) discussed the problems. These problems were also discussed in detail at the Penaeid Shrimp Workshop at Key West (1981). In discussing the strategy for fisheries management of Yellow Sea herring, we must consider:

(1) The economic benefits: The mature ovaries of herring are extremely valuable and an important export item, earning foreign exchange.

(2) According to the actual situation of Yellow Sea herring fisheries, any growth over-fishing can be accepted. Nevertheless, recruitment over-fishing must be prevented. For the Yellow Sea herring, there is no reliable evidence that there is any relation between adult abundance and recruitment. Under this circumstance it is still important to retain abundant spawners to prevent recruitment collapse.

As mentioned above, for the strategy of management of Yellow Sea fisheries a lower fork length of 230 mm. Limit for catches is equivalent to 2-years of age; trawlers are prohibited from operation from winter to the next spawning period. After these strategies are adopted, fishing mortality coefficient should decrease slightly, adult size should increase somewhat, but it will not have significant effects on stock size; the catch of trawlers will decrease seriously, their decreased catch will be compensated by the increased number of settled-nets near the shore, energy consumption will be reduced, the production of herring mature ovaries and the economic benefits of the whole herring fisheries will increase appreciably. These strategies have already been adopted by the fisheries management office.

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*YELLOW AND CHINA SEAS - MAR AMARILLO Y MAR DE LA CHINA*

# ON THE BIOLOGY AND FISHERY OF THE GOLDEN SARDINE (*Sardinella aurita* Val.) ALONG SOUTHERN FUJIAN AND EASTERN GUANGDONG COASTAL WATERS

by

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## Resumen

Los autores y sus colegas investigaron la biología y pesquería de la sardina dorada (*Sardinella aurita*) entre 1971 y 1977 y en el presente trabajo se resumen los principales resultados obtenidos. Para los estudios biológicos se colectaron y examinaron 7 022 especímenes en base a los cuales se llegó a determinar los siguientes aspectos de la estructura de la población:

La longitud del cuerpo varió entre 159 y 258 mm, la longitud promedio fue 185.2 mm, y el grupo dominante de tamaño se encontró entre los 160 y 210 mm. El peso del cuerpo varió entre 46 y 240 gr. Los grupos dominantes en cada año tuvieron pesos entre 50 y 70 gr. en 1971; 70 y 90 gr. en 1972; 80 y 100 gr. en 1973: 90 y 110 gr. en 1974; 70 y 90 gr. en 1975; y 110 y 130 gr. en 1976.

Se identificaron cinco grupos de edad (edad 0 a IV). Los grupos de edad predominantes entre los desovantes fueron variables: en los años 1971-1972 y 1975-1977 predominaron las edades I y II, y en los años 1973-1974 predominaron las edades II y III. Entre las edades I y II se observó un incremento en la longitud del cuerpo de 22.6 mm; 20.7 mm. entre las edades II y III, y 24.0 mm. entre las edades III y IV.

La proporción sexual hembras:machos fue 1:0.96 en 1972; 1:0.91 en 1975; 1:0.81 en 1976; y 1:0.94 en 1977.

La fecundidad promedio en 1972 (de 9 especímenes) fue 52 185 y en 1973 (12 especímenes) fue 70 720. En 1971 la mayor parte de los desovantes eran del grupo de edad I (160-180 mm), en 1972-74 la mayor parte de los desovantes fueron de edad mayor (180-200 mm).

El desove ocurre entre Marzo y Julio. Las áreas de desove se encuentran distribuidas en las aguas costeras (40-50 metros de profundidad) de la provincia del sur de Fujian y este de Guangdong, los límites del área de desove no están bien definidos.

Del análisis de 56 contenidos estomacales en 1972 y 144 contenidos estomacales en 1976 se observan resultados diferentes en cuanto al alimento dominante. En general *Sardinella aurita* es un pez zooplanctónico y su actividad alimentaria es baja.

Se han examinado los factores hidrológicos sobre pesca y cambios en los aspectos biológicos con la finalidad de explicar la causa del aumento y disminución de las capturas anuales, pero no se ha encontrado una explicación satisfactoria. Considerando la complejidad del problema, se propone un estudio más completo e intenso.

Estudios del comportamiento de los peces, la productividad del plancton, la extensión del afloramiento y mezcla de las corrientes, así como la relación con otros peces pelágicos, pueden ayudar a resolver este intrincado problema.

## INTRODUCTION

The golden sardine (*Sardinella aurita Val.*) is a pelagic warm water fish widely distributed in the warm part of the three great oceans. It also inhabits in coastal waters of the South China Sea and the southern part of East China Sea. Since the development of a purse-seine fishery using electric lights in the southeastern China coast in the middle sixty's, the annual catches of the sardine have greatly increased. According to and recognizing the incomplete statistics, the annual yield of the peak year (1971) amounted to 100,000 metric tons. The most important fishing ground lies in the coastal area of southern Fujian and eastern Guangdong province.

Since the early 1970's, an investigation into the biology and fishery of the golden sardine has been carried out by the author and colleagues. The following is a summary of the result of the investigations from 1971 to 1977.

## BIOLOGY OF THE GOLDEN SARDINE

Specimens of the golden sardine have been collected and measured since 1971 to study: the body length; weight and age composition; growth rate; spawning season and spawning ground; age at first sex maturation; sex ratio; fecundity; food composition and feeding intensity; etc. A total number of 7,022 specimens were examined within seven years of investigation.

### Body length

The body length (fork length) of the spring spawners ranges from 159 to 258 mm. The average recorded body length was 185.2 mm. The dominant body length group varies from year-to-year, ranging from 160 to 210 mm. Within the years of 1971-1977, there is a general increasing trend.

### Body weight

Body weight of the spring spawning population ranges from 46 to 240 g. (1971-1977). The dominant body weight groups are: 50-70 g. (1971), 70-90 g. (1972), 80-100 g. (1973), 90-110 g. (1974), 70-90 g. (1975), 110-130 g. (1976). The average body weights of the age groups I, II, III, and IV in the years 1971-1977 are given in Table 1.

Table 1. Average body weight of spring spawners of *Sardinella aurita*

| Age Group | I | II | III | IV | Specimen Examined |
|---|---|---|---|---|---|
| 1971 | 58.6 g. | 67.5 g. | 90.3 g. | -- | 117 |
| 1972 | 73.8 | 90.2 | 110.7 | -- | 143 |
| 1973 | 88.1 | 110.6 | 128.3 | 196.0 g. | 183 |
| 1974 | 93.0 | 98.5 | 137.3 | -- | 192 |
| 1975 | 97.2 | 127.5 | 175.0 | -- | 176 |
| 1976 | 120.0 | 138.8 | 162.5 | -- | 218 |
| 1977 | 109.0 | 143.2 | 169.6 | -- | 256 |

## Age Composition

Ages of the golden sardine are determined by the scale method. There are 5 age groups (0-IV) among the young and mature populations. The predominant age groups in spring spawners are I and II (1971-1972; 1975-1977), II and III (1973-1974) age groups. The summer populations are mostly 0 group, next is I group, the percentage of II and III age groups are very small.

## Growth rate

Based on the back calculation from aged specimens of the spawning population in 1972-1974. The average fork lengths of I, II, III and IV age groups is 171.1 mm, 193.7 mm, 214.4 mm, 238.4 mm, respectively. Hence, the body length increment is 22.6 mm from age I to age II, 20.7 mm from age II to age III, 24.0 mm from age III to age IV.

## Sex ratio

From data collected in 1972, 1973 and 1975 to 1977, the female spring spawners are usually slightly more numerous than the male. For example, the average sex ratio (♀ : ♂) is 1:0.96 in 1972, 1:0.88 in 1973, 1:0.91 in 1975, 1:0.81 in 1976, 1:0.94 in 1977.

## Fecundity

The average individual absolute fecundity was 52185 in 1972 (9 specimens) and 70720 in 1973 (12 specimens). Generally, the fecundity increases with body length and body weight but there is no definite regularity in our small samples.

## Age and length at first sex maturation

From observations on the maturity of gonads, the age at first sex maturation is considered to range from one year or two years old. In 1971, most of the spawners are of I age group (160-180 mm) while in 1972-1974, the majority are older groups II plus (180-200 mm). The smallest specimen observed at first sex maturation is 173 mm (♂), 174 mm (♀) in 1975.

## Spawning season and spawning ground

The spawning season lasts for a long period (March to August) in this area, but the peak season is from late March to May. The spawning ground situates in coastal waters (40-50 m, in depth) of southern Fujian and eastern Guangdong province, but the boundary is not exactly delimited.

## Food consumption and feeding intensity

An analysis of 56 stomach contents in 1972 showed that the food of adult fish differs considerably from that of young fish. The adult fish feed mainly on diatoms (*Nitzschia sp.*) and blue algae, next are small zooplankton such as copepods and ostracods. The young fish feed primarily on plantonic crustacea among which copepods and brachyuran larvae are the most important, secondary are diatoms (*Coscinodiscus spp.*) and fish larvae.

However, analysis of 144 stomach contents of the adult fish (fork length 170-230 mm) in 1976 showed quite different results. The majority of food items were planktonic copepods, decapods, brachyuran larvae, mysids, and chaetognatha, whereas the young fish (41-70 mm) fed mainly on diatoms (mostly *Coscinodiscus spp.*); next were copepods.

The feeding intensity is relatively low. Examination of the relative stomach fullness among the spawning season revealed that most had half full stomachs (Class II) or had less than 1/3 stomach filled with food (Class I). The summer young fish population had less full stomachs (mostly Class I).

## FLUCTUATIONS OF THE ANNUAL CATCHES OF THE SARDINE FISHERY

The annual catches of the sardine fishes of southern Fujian and eastern Guangdong provinces have increased since the development of the purse seine fishery employing electric lights in these coastal areas. The quantity of catches of southern Fujian in the years 1971-1978 are shown in Table 2.

Table 2. Quantity of Annual Catch of *S. aurita* of South Fujian

| Year | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|
| Annual catch (ton) | 20,101 | 12,462 | 3.495 | 5.696 | 5.650 | 1.813 | 7.47 | 14.416 |

From Table 2 it is clear that among the eight years (1971-1978) there are two peaks (1971, 1978) and two troughs (1973, 1976) of the annual yield.

The average catches per vessel in the years 1969-1978 are:

| | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|---|
| (ton) | 165.2 | 143.4 | 137.2 | 113.3 | 64.2 | 133.1 | 148.7 | 86.1 | 171.6 | 168.5 |

## ANALYSIS OF THE CAUSES OF FLUCTUATION OF ANNUAL CATCHES

The quantity of annual catches of any kind of marine fish may be influenced by three main factors:

(1) Changes of hydrological (such as temperature, salinity, currents, etc.) and meteorological factors (such as windy days, etc.);

(2) Changes due to fishing effort (such as over-fishing);

(3) Changes of biological factors (such as number of spawners, strong or weak generation, etc.).

Concerning the factor (1), there were no great changes overall in water temperature, salinity, or sea currents in the area discussed except that the water temperature in March 1973, was 1-2°C higher than that of the other years. This factor might influence the ripening of gonads hence the date of spawning season and finally the quantity of catch. But the effect is not so serious as to cause a sudden drop of the catch.

Concerning factor (2), the greatly increased fishing effort of the purse seine fishery with electric lights from 1969 to 1972 certainly has had profound effects. The most noted effect is diminishing the number of spawners, thence perhaps the number of larvae and young fish. The decline of catch in 1973 might be due to this factor. But the fact that the annual catch of the golden sardine has gradually recovered and another peak was observed in 1978 cannot be explained relative to fishing alone. Particularly since the fishing intensity from 1971 to 1977 increased rather than decreased.

Concerning factor (3), the weak generation of the year-class of 1973 might have influenced the magnitude of catches in 1974-1976, so the subsequent decline of catch in 1976 may be attributed to this factor. However, why the catch of 1978 reached another peak is not certain. Maybe it was due to the strong year-class of 1975. It should be noted that the catches of other pelagic fishes such as round scad (*Decapterus maruadsi*), the Japanese mackerel (*Scomber japonicus*) and the round herring (*Etrumeus micropus*), etc. were all good in the same year.

Thus, what are the true factors controlling the fluctuation of annual catches? At present it is quite difficult to answer. Considering the complexities of this question, more thorough and intensive studies are needed, including fish behaviour (distribution, migration, feeding and breeding), plankton productivity, the extent of upwelling and mixing of water masses and currents as well as the interrelationship of other pelagic fishes, etc. These must be combined and employed as comprehensive tools to resolve this intricate problem.

*EASTERN CENTRAL PACIFIC - PACIFICO CENTRO-ORIENTAL*

# VARIABILITY OF PELAGIC FISH STOCKS OFF CALIFORNIA

by

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## Resumen

Los stocks de peces pelágicos costeros de California muestran una variedad de patrones de fluctuación. Los stocks de sardinas del Pacífico se redujeron drásticamente por la excesiva presión de pesca, y su recuperación ha sido lenta. Algún tiempo después de la reducción de la sardina, la anchoveta aumentó, alcanzando aparentemente una abundancia de equilibrio a mediados de los años 1960. Tanto California como México han desarrollado pesquerías de reducción de anchoveta, y el stock está ahora plenamente explotado. El stock de caballa fue reducido a mediados de los años 1960. Pero ahora se ha ido rehabilitando debido a un reclutamiento favorable y a una explotación estrictamente controlada, y en estos momentos sostienen una pesquería saludable. El jurel es un recurso grande y prácticamente no explotado a excepción de una pequeña pesquería en las áreas de cría frente a la parte sur de California. El bonito del Pacífico es una población marginal que recientemente se ha establecido en las aguas al sur de California y su permanencia es cuestionable. El recurso de barracuda de California también está reducido, pero la composición por edades está respondiéndo favorablemente a una limitación del tamaño mínimo de pesca. El estado del robalo blanco de mar es poco claro, pero el recurso está posiblemente sobreexplotado.

La variabilidad de los recursos de peces pueden generarse por muchas causas. Las fluctuaciones del reclutamiento son partícularmente importantes para especies de vida corta. El reemplazamiento de especies parece ocurrir, pero es favorecido o ocurre a través de cambios ambientales. Contrario a las asunciones estándar, los cambios en la tasa de mortalidad natural pueden ser una causa importante de las fluctuaciones en abundancia.

## INTRODUCTION

This paper is divided into two sections; the first reviews historical fluctuations in abundance of several pelagic fishes and larger predatory fishes off California. The second section examines assorted pieces of evidence relating to mechanisms causing those fluctuations.

## HISTORICAL REVIEWS

### Pelagic fishes

#### California Sardine *Sardinops sagax caerulea*

Population analyses by Murphy (1966) and MacCall (1979) document the history of the Pacific sardine stock (here termed the California sardine to avoid confusion). When plotted on a logarithmic scale (Figure 1), the decline in abundance appears as a coherent trend extending over the entire thirty years of the historical fishery. There are no discontinuities which could be interpreted as adverse environmental changes. Rather, the sustained rate of decline (average instantaneous rate of increase is approximately -0.2/yr) suggests that the fishery consistently exceeded sustainable yields by about 18 percent.

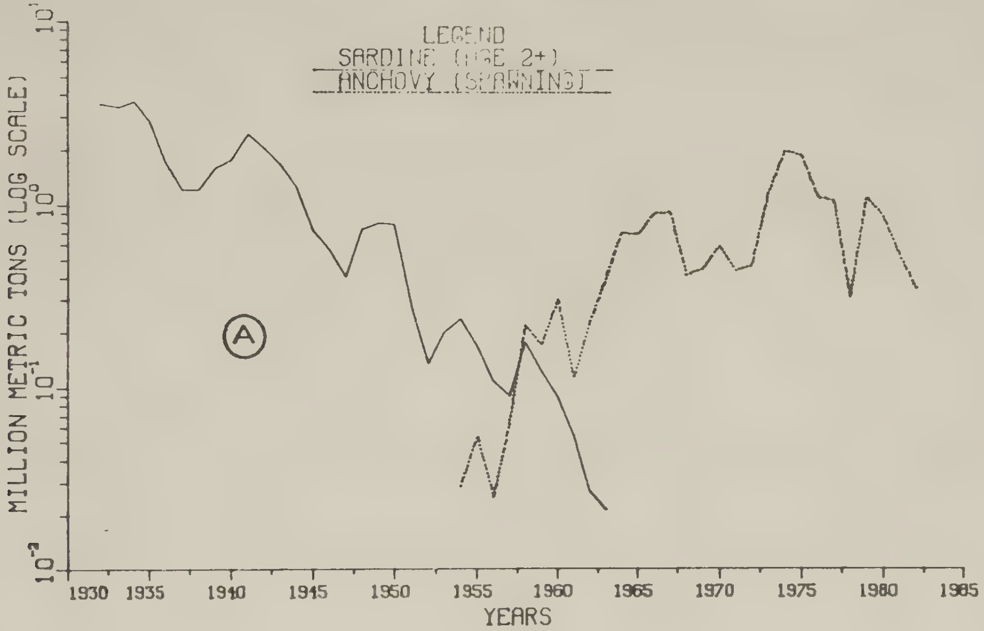


Figure 1. Time series of sardine (age 2+) and anchovy spawning biomass (log scale) off California and northern Baja California. "A" denotes approximate anchovy spawning biomass in 1940-41 (interpreted from Smith 1972).

Exploitation continued until 1970, when a moratorium on sardine landings was enacted by the State of California. During the following decade the resource remained at nearly undetectable levels, and showed no signs of recovery until 1980, when sardines became increasingly frequent as incidental catches in landings of other pelagic fishes. Abundance has increased noticeably as of 1982. A 1982 pelagic fish survey captured sardines in 14 midwater trawl tows, whereas sardines had occurred in only three other tows in the entire previous 20 years of surveys (Mais 1982). A small fishery will be allowed when the stock reaches a biomass of 20,000 tons, which is a possibility in the near future.

#### Northern Anchovy *Engraulis mordax*

Understanding of northern anchovy population fluctuations has been revolutionized by recent development of an "egg production method" of biomass estimation (see Parker 1980, Picquelle and Hewitt 1983 in press). Previous population estimates based on larva abundance have been insensitive to changes in true population abundance because egg and larval mortality rates are positively correlated with initial egg production (Hewitt 1982), and hence adult abundance. Since 1980 anchovy abundance estimated (over the range of the stock by an ichthyoplankton survey) by the daily fecundity per gram of adult fish (estimated by histological examination of ovaries from adult fish, see Hunter and Goldberg 1980). The resulting egg production biomass estimates have been lower than simultaneous estimates of larva census biomass. The difference is due probably to an erroneous prior assumption concerning relative spawning frequencies of anchovies and sardines. Whereas the two species off California were assumed to spawn with equal frequency (Smith 1972), recent egg production method surveys in Peru indicate that the anchoveta *Engraulis ringens* spawns more frequently than does the sardine, *Sardinops sagax* (J. Alheit, PROCOPA, c/o IMARPE, Callao, Peru, personal communication).

By extrapolating egg and larva abundance-at-age back to the time of spawning, Lo (Southwest Fisheries Center, La Jolla, California, manuscript in preparation) has calculated an index of historic egg production. This index was analyzed by MacCall (1982) and Methot (1982) to produce a time series of estimated anchovy spawning biomasses from 1954 to 1982 (Figure 1). From very low abundance in the early 1950's, anchovy abundance increased, reaching an erratic equilibrium beginning about 1964. The increase in anchovy abundance lagged the sardine decline, and did not occur until sardine abundance dropped to one-tenth of its peak value. Whereas previous analyses indicated a peak anchovy abundance of four to five million mtons in 1964-66 (MacCall 1980), the new time series shows peak biomasses of about two million mtons to have occurred a decade later. Tentative biomass estimates for 1940-41 have been added to the time series, based on Smith's (1972) larva census estimates which are very similar to larva censuses for 1957-58 (Figure 1).

A reduction fishery was initiated in California in 1966, and a Mexican fishery expanded in the mid-1970's. Total annual harvests in 1980 and 1981 were about 300,000 mtons, very near the estimated MSY. Thus, the northern anchovy is "fully utilized" by common fishery standards. Recruitment has been highly variable since 1974, and has been declining since 1978. Unless recruitment improves, the anchovy resource is likely to continue to decline in abundance, given the current rate of exploitation.

### Pacific Mackerel *Scomber japonicus*

Historical abundance of Pacific mackerel has been calculated by Parrish and MacCall (1978). Due to a string of very strong year classes, abundance in the 1930's probably exceeded average virgin stock levels (Figure 2; the fishery began about 1928). Over the following years spawning success (recruits per spawner) varied with a distinct six- to seven-year cycle which ended with collapse of the resource about 1965. A moratorium on Pacific mackerel catches was enacted by the State of California in 1970, and in 1972 the moratorium was supplemented by a formula for future harvests based on estimated stock abundance.

Subsequent recovery of the resource is documented by a series of annual reports to the California legislature (Richard Klingbeil, California Department of Fish and Game, Long Beach, California, unpublished reports). During the 1970's relatively strong recruitments occurred in even years (1972, 1974, 1976, 1978), showing a very different pattern of spawning successes than had occurred previously. The 1976 year class was sufficient to allow opening of a small fishery in 1977-78. The subsequent 1978 year class is probably the largest in the documented history of the fishery, and has supported increased harvests. The fishery and resource are now at historically high levels (Figure 2), and prospects are good that the fishery will continue indefinitely (at varying levels) under the present program of management.

### Jack Mackerel *Trachurus symmetricus*

No substantial fishery has developed for jack mackerel in California or Mexico. A small fishery for young fish (less than age six) off southern California has existed since 1950, but the industry has had difficulty marketing the product. Much of the biomass consists of large adults in oceanic waters ranging from sourthern Baja California to the Aleutian Islands, and as much as 1500 km offshore. These fish may exceed 30 years of age (Fitch 1956), and stock size may be around two million mtons (MacCall and Stauffer 1983 in press).

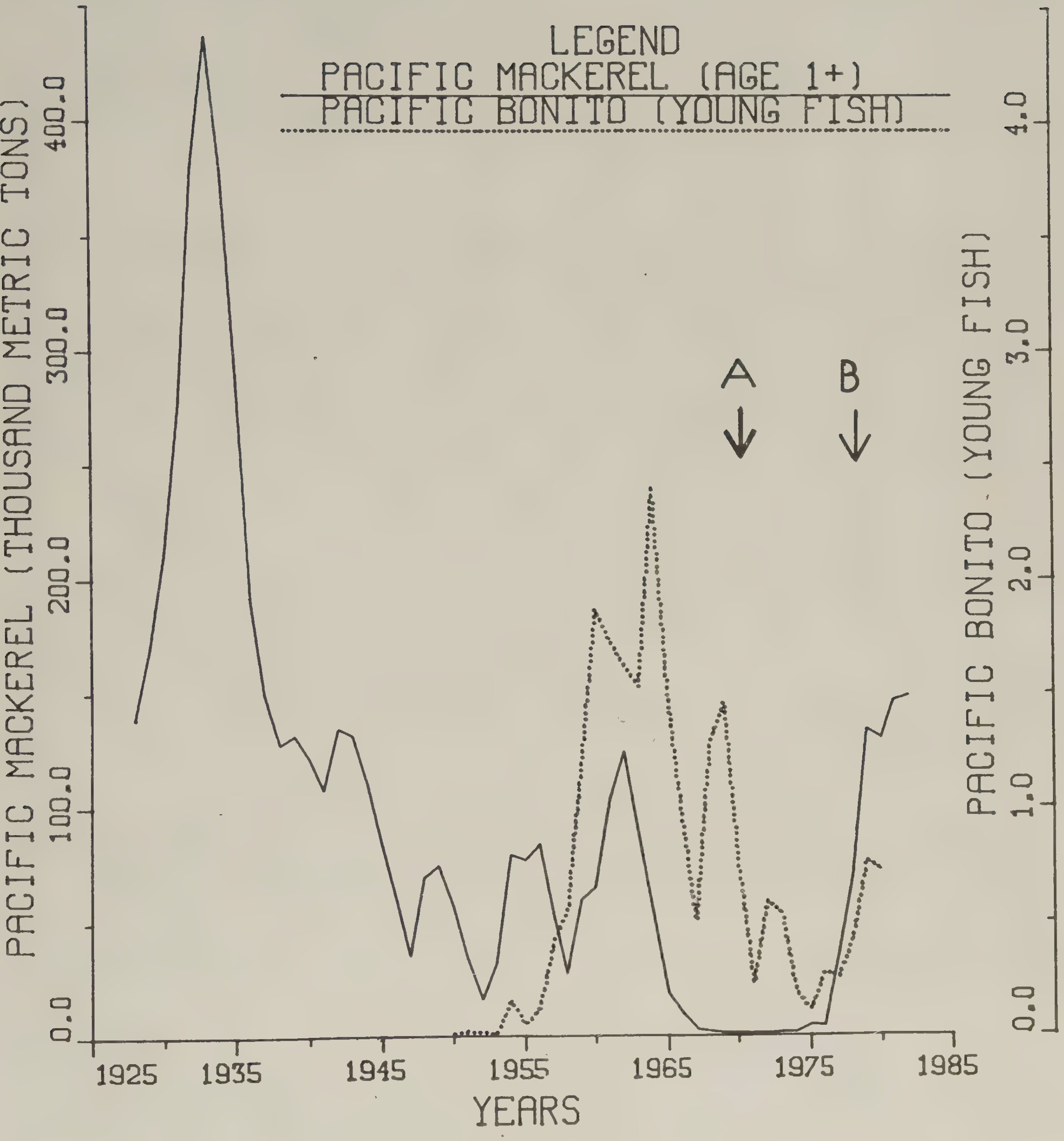


Figure 2. Time series of Pacific mackerel total biomass (age 1+) and Pacific bonito catch-per-effort. "A" denotes beginning Pacific mackerel fishing moratorium, and "B" denotes re-opening of the fishery.

Nearly all the spawning occurs in oceanic waters far from shore; however, subsequent young-of-the-year appear inshore, mainly off southern California. Recruitment strength is highly variable (Figure 3). Virtual recruitment strength was calculated by summing the percentage contributions of each year class to the fishery over the duration of the cohort. Strong year classes tend to be isolated by several weak year classes, with a suggestion of periodicity. Age compositions for more recent catches are unavailable, but the 1976 and 1982 year classes seem to be relatively prominent.

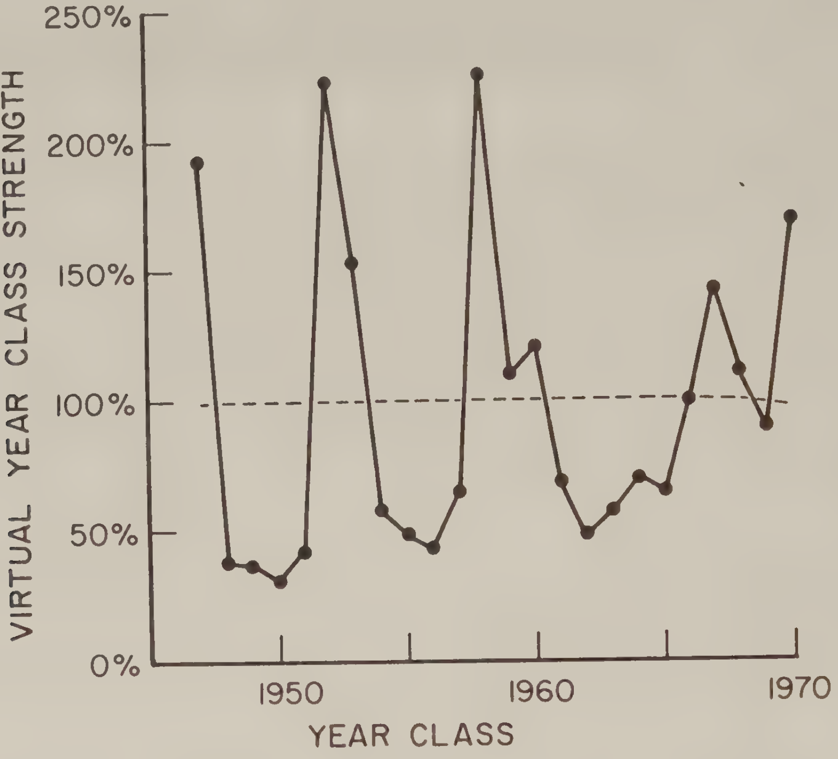


Figure 3. Virtual year class strengths of jack mackerel off California (from MacCall and Stauffer 1983).

## LARGER COASTAL PREDATORY FISHES

Information on many of these fishes tends to be limited to catch histories and scattered biological observations with little continuity. Many of these fishes are migratory, with the bulk of the populations residing in Mexican waters. Migration strength is strongly associated with large scale ocean temperature anomalies (Radovich 1961), and the resulting environmental noise may conceal trends in stock abundance. These species are popular targets of both recreational fisheries and commercial fisheries, with catches of roughly equal magnitude.

### Pacific Bonito *Sarda chiliensis*

Pacific bonito have long been visitors to California waters, with large adults appearing off southern California in the late summer and fall. However, an apparently self-sustaining younger population seems to have established residence in southern California waters only since the mid-1950's (see Collins et al. 1980 for a complete review). Recreational anglers catch mostly young fish, and catch-per-angler-trip is the best available index of the non-migrant stock (Figure 2).

Abundance has declined since the early 1960's. Some of that decline must be attributed to the commercial fishery which began harvesting bonito in 1966, but sustainability cannot necessarily be expected from a resource which has only recently come into existence. The bonito stock off California is a marginal population which hovers near the edge of viability--one hypothesis is that warm-water discharges from power generating stations have provided overwintering refuges for fish that would normally migrate south (Robson Collins, California Department of Fish and Game, Long Beach, California, personal communication). Faced with increasingly intense exploitation of pre-spawning fish, a minimum size regulation was implemented in 1982 in order to protect fish through their first spawning season. This management measure should help to maintain a southern California bonito stock during those periods when conditions are favorable.

### California Barracuda *Sphyraena argentea*

Catch rates and size composition declined severely in the 1960s, leading to imposition of a strict size limit in 1972. This regulation caused a severe drop in U.S. recreational landings, but size composition has improved steadily over the past decade. Numerical abundance has shown little increase, but the improved spawning capacitiy of the stock has improved the prospects for recovery (Schultze 1983).

### White Seabass *Atractoscion nobilis*

Recreational catch per effort has declined severely over the last 25 years, but commercial catch rates have remained relatively constant. Once abundant as far north as San Francisco, the range has steadily contracted southwards under exploitation (Collins 1982, Vojkovich and Reed 1983), indicating that population size may have declined more than local density would suggest. Mortality rate estimates calculated for the period 1958-60 (Thomas 1968) indicate that the fishing mortality rate (F) considerably exceeded the natural mortality rate (M). Perhaps due to the strong immigration of white seabass during the anomalously warm period of Thomas' study, he advocated increased fishing intensity. However, in light of more recent "rules-of- thumb" (e.g. Alverson and Pereyra 1969, Gulland 1970), which suggest that F is near M at MSY, the above relationship gives reason to suspect overfishing.

## CAUSES OF FLUCTUATIONS

Fluctuations in fish stocks are caused by complex interactions of fishery, biological, and environmental factors. The social and economic tragedy that accompanies fishery collapses calls for "explanations," whereby people are eager to lay blame on the environment, the fishermen, or the government. There has been an unfortunate tendency toward simplistic single-factor explanations, and available data often are insufficient to explore more complicated hypotheses. In addition, scientists may interpret and "filter" data in favor of rationalizations and preconceived assumptions (Gould 1978). I suspect that analyses of stock fluctuations are especially prone to this problem. With hindsight, we can usually prescribe a management policy which would have averted the tragedy; such wisdom is much more difficult to apply with foresight. However, now with the cumulative experience of scores of similar fisheries and resources around the world, observed over decades of variability, fishery management is emerging from unexplored territory into a realm where experience provides a reliable guide. There will always be risk associated with these fluctuations; some of that risk can be reduced by appropriate resource management, and the remainder must be recognized as an unavoidable characteristic of the resource.

The fisheries and oceanography of the California Current are among the most thoroughly studied in the world. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) Program, established over thirty years ago as a response to the collapsing sardine fishery, has provided a remarkable fishery-independent data base of physical and biological observations. This local knowledge is supplemented by experience in several analogous eastern boundary currents including those of Peru and South Africa (e.g. Bakun and Parrish 1980, 1982). This accumulation provides evidence for several mechanisms causing variability in coastal pelagic fish stocks, some of which will be reviewed briefly here (also see Lasker and MacCall 1983 in press).

### Variability of Recruitment

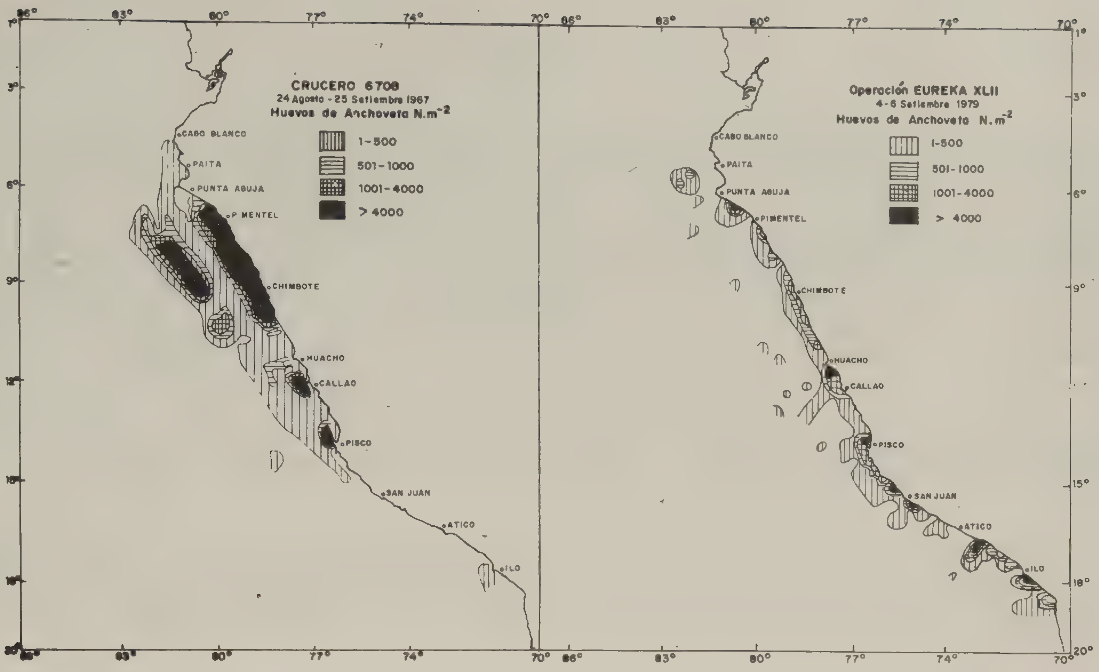
Causes of recruitment variability is a popular area of fishery research, especially for coastal pelagic fishes (see Lasker 1981, and Sharp 1980 for reviews). As a source of stock fluctuations, recruitment variability is important in three cases: short-lived fishes, age class-specific fisheries, and high serial correlation of reproductive success. Population size behaves as an exponential moving average of recruitment strengths; variability of population size is therefore a function of the variability of recruitment itself and of the exponential decay coefficient or mortality rate. Fishes may be short-lived due to high natural mortality rates (e.g. anchovies) or due to high total (natural plus fishing) mortality rates (e.g. sardines). In the latter case, reduction of fishing intensity may help stabilize population fluctuations by averaging recruitment over longer periods. Age class-specific fisheries occur often as nursery ground fisheries such as the southern California jack mackerel fishery. Empirical probability distributions of reproductive variability can be developed in both of these cases. However the third case of high serial correlation is more insidious. The long-term probability distribution may be an inadequate description of near-term behavior, as near-term probabilities are conditional on current environmental or stock status. During long periods of good recruitment, the fishery may become overcapitalized. This tends to delay appropriate reductions in fishing intensity during the inevitable succeeding period of poor recruitment.

## Climatic Change and Species Replacement

There is some dispute as to whether climatic regimes are distinguishable from the patterns of variability arising simply from an autoregressive mechanism. As in any correlation study, empiricalserial correlation spectra cannot be used to infer mechanisms, and existing time series of physical observations tend to be too short to test more sophisticated hypotheses. Recently Shuntov and Vasil'kov (1982) have suggested that sardine and anchovy variability may be driven by solar periodicity. Whichever the physical cause, biological systems tend to respond with regimes--protracted periods of similar behavior with abrupt transitions to a different mode of behavior.

The supposed "competitive replacement" of the sardine by the anchovy in California has now become a textbook case; the simulation study by Silliman (1969) was cited in Odum's (1971) ecology text as substantiation of the Volterra competition equations (Radovich 1981). This conclusion is very attractive to theoretical ecologists, whose mathematical models often have found little support in the real world. However, closer inspection (Daan 1980), and the following geographic argument severely weaken the case for simple competitive replacement.

The most important argument against competitive replacement is that the anchovy and sardine stocks have not occupied the same habitats. Typically, sardine stocks are distributed polewards of the respective anchovy stocks: The California sardine was abundant from Baja California to British Columbia, with a large portion of the population north of Pt. Conception, whereas the northern anchovy resides mostly south of Pt. Conception. Similarly, the Peruvian sardine is now abundant in northern Chile, whereas the previous anchoveta stock was scarce south of Pisco. There is evidence that the anchoveta resource has recently shifted southwards as well (Figure 4). A similar poleward shift in Peruvian fish production, although of unknown species composition, has been suspected for early historic times (Hutchinson 1950: p48), "It is also noteworthy that the rather unproductive region south of Pisco Bay, as far south as Iquique, seems from the 16th to the early 19th centuries to have been regarded as a more important source of guano than the central Peruvian coast...the only reasonable, though admittedly speculative, explanation of the decline of importance of the southern islands...is that minor changes in the dominant hydrographic pattern have occurred, tending to alter the distribution of the centers of abundant fish". Under the competitive replacement hypothesis, the replacing species should occupy the habitat of the former competitor. This does not seem to be the case for anchovies and sardines. Rather, geographic shifts of stock distribution indicate large scale environmental influences.


CRUCERO 6708
24 Agosto - 25 Setiembre 1967
Huevos de Anchoveta N.m$^{-2}$
1-500
501-1000
1001-4000
> 4000
CABO BLANCO
PAITA
PUNTA AGUJA
P MENTEL
CHIMBOTE
HUACHO
CALLAO
PISCO
SAN JUAN
ATICO
ILO
Operación EUREKA XLII
4-6 Setiembre 1979
Huevos de Anchoveta N.m$^{-2}$
1-500
501-1000
1001-4000
> 4000
CABO BLANCO
PAITA
PUNTA AGUJA
PIMENTEL
CHIMBOTE
HUACHO
CALLAO
PISCO
SAN JUAN
ATICO
ILO
86°
83°
80°
77°
74°
70°
1°
3°
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9°
12°
15°
18°
20°

Figure 4. Sampling area and geographic distribution of anchoveta egg samples before and after 1971 (from Santander et al, 1982).

## Variability of Natural Mortality Rates

Fishery models invariably assume a constant rate of natural mortality. Whether or not this is valid, fishery modelers have taken comfort in a long tradition of making this assumption. The quantity of fishery-independent information on California's anchovy stock has allowed Methot (1982) to attempt to reconcile age compositions with independent estimates of stock abundance. He concluded that the high anchovy biomass in the mid-1970s was not simply the product of strong recruitment, but rather was due to a substantial decrease in the natural mortality rate. If variability in natural mortality rate is a major factor in variability of pelagic fish stocks, methods such as cohort analysis are unreliable, and fishery-independent estimates of abundance are necessary. On the other hand, patterns of known variation in M may lead to development of meaningful multispecies fishery management models.

## CONCLUSIONS

California coastal pelagic fish stocks show a variety of patterns of fluctuations. Pacific sardines have been depleted by excessive fishing pressure, and have been slow to recover. With some delay following the decline of the sardine, anchovies increased, reaching apparent equilibrium abundance in the mid-1960's. Both California and Mexico have developed reduction fisheries on anchovy, and the stock is now fully exploited. Pacific mackerel were depleted by the mid-1960's, but now have been rehabilitated due to favourable recruitment and strictly controlled harvest, and support a healthy fishery. Jack mackerel is a large resource, unfished except for a small fishery on the nursery grounds off southern California. Pacific bonito is a marginal population having recently established itself in southern California waters, and sustainability is questionable. The California barracuda resource is depressed, but age composition is responding favourably to a minimum size limit. The status of white seabass is somewhat unclear, but the resource is probably overexploited.

Variability in fish stocks can arise from many causes. Recruitment fluctuations are particularly important for short-lived fish. Species replacement seems to occur, but is environmentally mediated. Contrary to standard assumptions, changes in the rate of natural mortality of adults may be an important cause of fluctuations in abundance.

## ACKNOWLEDGEMENTS

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*SOUTH-EAST PACIFIC - PACIFICO SUDORIENTAL*

# VARIABILIDAD DE LOS RECURSOS PELAGICOS EN EL PACIFICO SUDESTE

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## Summary

The principal pelagic communities of the southeast Pacific are described, as are their characteristic variations in time.

Guano bird population and distribution is discussed in relation to anchoveta population changes.

The nature of changes in abundance and distribution of resources since the 1972-1973 El Niño are considered, particularly in regard to the intensity and changes in fishing effort and also in regard to the carbon cycling within various trophic components.

The continuous, long-term variation of these resources are also discussed in relation to sediment records.

## INTRODUCCION

Las comunidades naturales, al igual que sus poblaciones, están cambiando permanentemente como consecuencia de un proceso natural de desarrollo de los ecosistemas del que forman parte; cambios que por lo regular son lentos. Pero existen otros, casi tan violentos y como tal espectaculares, que afectan notablemente la magnitud de las poblaciones y la composición de especies de la comunidad.

Uno de estos cambios, de gran impacto socio-económico en las pesquerías de los países del Pacífico Sureste, es el de la anchoveta (*Engraulis ringens*) que a partir de 1972 disminuyó desde una biomasa del orden de 20 a 30 millones de toneladas a tan sólo 2 a 3 millones de toneladas, produciéndose simultáneamente la expansión de especies poco abundantes hasta entonces, como la sardina (*Sardinops sagax*), jurel (*Trachurus s. murphyi*) y caballa (*Scomber japonicus*).

Paralelamente otras especies relacionadas íntimamente con la anchoveta, como las aves productoras de guano disminuyeron.

La ocurrencia del fenómeno oceanográfico de El Niño y la pesca intensa son elementos que se analizan en relación a cambios más notables en número y estructura de especies, con cierto énfasis en el examen histórico de los principales predadores de la anchoveta, las aves productoras de guano, a las que se considera como valioso indicador por su respuesta frente a cambios del ambiente y a las actividades del hombre.

## PRINCIPALES COMUNIDADES PELAGICAS NERITICAS EN EL PACIFICO SURESTE

En el Pacífico Sureste se distinguen tres zonas biogeográficas claramente definidas, que responden a características propias del medio ambiente:

a) La Provincia Panameña que abarca desde Baja California hasta el extremo norte del Perú, caracterizada por un ambiente tropical, con temperaturas superficiales del mar de 28°C, con pocas variaciones durante todo el año, y salinidad de 33 o/oo. La productividad tiene valores de unos 180 gr C/m$^2$/año (SMAYDA, 1966) y fuera del Golfo de 100gr C/m$^2$/año (BLAKBURN, 1966).

En esta Provincia, los principales recursos de las comunidades pelágicas están representados por:

*Cetengraulis mysticetus*
*Anchoa panamensis*
*Anchoa naso; y A. nasus*
*Opisthonema libertate*
*Etrumeus teres*
*Scomber japonicus*

b) La provincia Peruano-Chilena, que comprende el área desde Punta Aguja, Perú (06°S) hasta Chiloe, Chile (42°S), corresponde a un típico ecosistema de afloramiento costero donde la alta productividad genera una biomasa de plancton muy alta, capaz de transformar 113 x 10$^6$ toneladas métricas de carbón por año (CUSHING, 1969). Las temperaturas relativamente bajas, fluctúan entre los 15 a 20°C y la salinidad es de 35 o/oo. La productividad ha sido calculada en unos 438 gr C/m$^2$/año frente a las costas del Perú (GUILLEN y MENDIOLA, 1974) y el oxígeno disuelto hasta en 7 ml/L, en la superficie, cayendo bruscamente a valores de 0.5 ml/L o menores por debajo de los 50 m (ZUTA y GUILLEN, 1970).

Las comunidades pelágicas típicas de esta región están representadas por las siguientes especies que constituyen recursos pesqueros:

*Engraulis ringens*
*Sardinops sagax*
*Brevoortia maculata*
*Trachurus symmetricus murphyi*
*Scomber japonicus*
*Sarda sarda chiliensis*
*Seriolela violacea*
*Scomberesox saurus*

Por su estrecha relación con los recursos pelágicos, particularmente con la anchoveta, se debe mencionar también a las 3 especies productoras de guano que constituyen elementos típicos de las comunidades pelágicas de esta región:

*Phalacrocorax bougainvillii*
*Sula variegata*
*Pelecanus occidentalis thagus*

c) La Provincia Patagónica, que abarca desde Chiloe, Chile, hasta el extremo sur del continente, está caracterizada por temperaturas bajas-menores de 14ºC. Salinidad alrededor de 44 o/oo y alta productividad. En esta zona principalmente la gran turbulencia del agua en los estratos superiores es un factor claramente limitante para los recursos pelágicos, siendo por ello más abundantes los demersales.

Entre los recursos pelágicos de importancia se puede mencionar a:

*Clupea (Strongomera) bentincki*
*Clupea fuegensis*
*Normanichsthys crockeri*

Debido a la escasez de información para la mayoría de especies mencionadas, tanto desde el punto de vista de estadísticas pesqueras y menos aún sobre evaluaciones poblacionales y ecológicas, sólo es posible vislumbrar y analizar los grandes cambios que se vienen produciendo en las comunidades frente al Perú y Chile, principalmente en las poblaciones con más incidencia económica. Aún así, debido a que las pesquerías son jóvenes, las estadísticas útiles y comparativas son muy recientes y no sobrepasan dos décadas. En este sentido, las fluctuaciones de las poblaciones de las aves guaneras, tan estrechamente relacionadas con la anchoveta, su principal alimento, sirven de valioso complemento, ya que las informaciones se remontan a cerca de un siglo.

La anchoveta ha sido el sostén de las poblaciones de aves marinas más grandes del mundo y su preponderancia en la comunidad de recursos pelágicos de la región ha sido reportada por investigadores del siglo pasado, tales como Rivero y Ustariz, Humbolt y Raimondi.

Teniendo en consideración que para principios del presente siglo se reconoció el establecimiento de un sistema trófico complejo en la costa peruana, con la anchoveta como eslabón central para la distribución de energía en un amplio espectro de especies, se puede asumir que la anchoveta *E. ringens* fue la especie preponderante por mucho tiempo, luego de un largo proceso de sucesión ecológica.

MURPHY (1925), VOGT (1942), SCHWEIGGER (1964) y en forma más específica KOEPCKE (1952) determinan la posición ecológica de la anchoveta; y su preponderancia, en términos cuantitativos, fue establecida por EINARSSON Y ROJAS DE MENDIOLA (1966).

Estudios geológicos realizados frente al Perú mostraron que cerca del 79% de escamas encontradas en los sedimentos correspondían a la anchoveta, durante milenios (11 a 12.000 años) y los de sardina se presentaron sólo en forma intermitente y por períodos cortos (De Vries, 1979, citado por MATHISEN, 1979).

## CARACTERISTICAS DE LA VARIABILIDAD DE LOS RECURSOS PESQUEROS

Considerando que las poblaciones naturales están permanentemente cambiando y que ellas responden a una serie de factores intrínsecos y extrínsecos, se reconocen los siguientes tipos de cambios:

a) Variaciones estacionales e interanuales como consecuencia del proceso reproductivo y de crecimiento;
b) Variaciones de período medio, como consecuencia de cambios drásticos en el medio ambiente y/o debido a la acción del hombre; y,
c) Variaciones de largo período que se relacionan con la evolución natural de las comunidades (sucesión) debido a la interacción entre poblaciones principalmente por predación y competencia, o por cambios persistentes del medio ambiente.

En lo que sigue nos referimos principalmente a los cambios del tipo (b).

Una primera aproximación, por lo menos de los grandes cambios se desprende al examinar las estadísticas de captura en el Pacífico Sudeste, considerando las especies más importantes (Tabla 1 y Tabla 2). Se considera el período de 1964 a 1980, porque corresponde al de la gran expansión de las pesquerías en las cuales se presentan los máximos de captura debido al gran esfuerzo desplegado y los mínimos como consecuencia de la disminución en la disponibilidad de los stocks.

TABLA 1.- ESTADISTICAS PESQUERAS DE LAS PRINCIPALES ESPECIES PELAGICAS EN EL PACIFICO SUDESTE

(Miles de toneladas) ( 1964 - 1972 )

| | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | PAISES |
|---|---|---|---|---|---|---|---|---|---|---|
| Anchoveta | 934.0 | 438.5 | 1,090.8 | 705.4 | 1,008.9 | 743.3 | 782.9 | 960.9 | 367.9 | Chile |
| *Engraulis ringens* | 8,863.4 | 7,242.4 | 8,529.8 | 9.824.6 | 10,262.7 | 8,960.5 | 12,277.0 | 10,276.8 | 4,447.4 | Perú |
| Sardina | 37.4 | 43.0 | 62.1 | 122.4 | 93.5 | 116.5 | 68.1 | 174.7 | 131.7 | Chile |
| *Sardinops s. sagax* | 10.2 | 7.4 | 1.9 | 2.1 | 1.8 | 1.1 | 0.5 | 6.1 | 6.3 | Perú |
| Machete | -- | 0.1 | 0.2 | 0.3 | 0.1 | 0.2 | 0.7 | 0.4 | 0.5 | Chile |
| *Brevoortia maculata* | -- | 7.0 | 13.4 | 18.4 | 11.9 | 13.0 | 19.7 | 22.8 | 42.1 | Perú |
| Jurel | 10.3 | 12.7 | 17.6 | 26.4 | 23.8 | 16.6 | 112.0 | 158.4 | 87.0 | Chile |
| *Trachurus s. murphyi* | 1.7 | 2.6 | 4.3 | 3.1 | 2.8 | 4.2 | 4.7 | 9.2 | 18.8 | Perú |
| Caballa | -- | -- | -- | -- | -- | -- | -- | -- | -- | Chile |
| *Scomber japonicus* | 2.0 | 3.8 | 7.6 | 13.4 | 7.2 | 7.2 | 8.8 | 10.1 | 8.7 | Perú |
| Bonito | 6.2 | 11.1 | 12.8 | 8.6 | 4.1 | 5.9 | 4.5 | 1.7 | 4.6 | Chile |
| *Sarda s. chiliensis* | 80.6 | 62.3 | 71.4 | 63.6 | 54.3 | 59.3 | 57.4 | 73.0 | 64.2 | Perú |
| Pinchagua | 6.6 | 7.1 | 8.1 | 8.5 | 21.3 | 23.8 | 35.0 | 41.9 | 55.2 | Ecuador |
| *Opistonema libertate* | 0.0 | 0.0 | 12.9 | 27.3 | 12.2 | 13.0 | 6.0 | 5.8 | 14.3 | Panamá |
| Anchoveta | -- | -- | -- | -- | -- | -- | -- | -- | -- | Colombia |
| *Cetengraulis mysticetus* | -- | 33.0 | 53.1 | 38.0 | 53.2 | 8.7 | 28.6 | 51.6 | 34.5 | Panamá |
| | -- | 9.3 | 13.4 | 22.5 | 15.7 | 3.9 | 5.1 | 3.8 | 6.1 | México |

1964/1969: Anuario Estadístico de FAO, Vol. 30-1970

TABLA 1 (cont.) ESTADISTICAS PESQUERAS DE LAS PRINCIPALES ESPECIES PELAGICAS EN EL PACIFICO SUDESTE

(Miles de toneladas) ( 1973 - 1981 )

| | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | PAISES |
|---|---|---|---|---|---|---|---|---|---|---|
| Anchoveta | 191.8 | 381.8 | 239.8 | 434.0 | 18.7 | 229.0 | 50.6 | 102.7 | 325.1 | Chile |
| *Engraulis ringens* | 1,768.7 | 3,583.5 | 3,078.8 | 3,863.1 | 792.1 | 1,187.0 | 1,362.8 | 720.1 | -- | Perú |
| Sardina | 187.5 | 391.1 | 231.7 | 355.4 | 620.8 | 732.8 | 1,618.9 | 1,772.7 | 1,620.2 | Chile |
| *Sardinops s. sagax* | 60.5 | 72.6 | 62.9 | 174.7 | 870.9 | 1,257.9 | 1,727.2 | 1,480.4 | -- | Perú |
| Machete | 2.1 | 0.9 | 0.7 | 0.5 | 0.4 | 0.8 | 1.0 | 1.5 | -- | Chile |
| *Brevoortia maculata* | | 16.7 | 3.0 | 2.7 | 5.2 | 6.3 | 2.8 | 11.1 | -- | Perú |
| Jurel | 121.6 | 196.2 | 261.2 | 342.3 | 340.8 | 586.7 | 597.5 | 562.3 | 1,059.4 | Chile |
| *Trachurus s. murphyi* | 42.8 | 127.5 | 37.9 | 54.2 | 505.0 | 386.8 | 151.6 | 123.2 | -- | Perú |
| Caballa | -- | -- | -- | -- | 141.3 | 182.7 | 89.1 | 102.3 | 97.5 | Chile |
| *Scomber japonicus* | 65.0 | 63.3 | 23.6 | 40.2 | 46.1 | 101.5 | 118.0 | 59.0 | -- | Perú |
| Bonito | 4.4 | 1.0 | 0.1 | 0.3 | 2.9 | 2.4 | 3.8 | 2.7 | 2.7 | Chile |
| *Sarda s. chiliensis* | 34.8 | 7.4 | 4.9 | 4.1 | 5.7 | 4.7 | 5.3 | 6.7 | -- | Perú |
| Pinchagua | 95.0 | 110.0 | 140.0 | 225.0 | 370.0 | 550.0 | 574.8 | 593.1 | -- | Ecuador |
| *Opistonema libertate* | 20.5 | 36.7 | 20.1 | 16.6 | 23.4 | 20.3 | 15.7 | 23.3 | -- | Panamá |
| Anchoveta | -- | 0.8 | 17.1 | 2.9 | 4.6 | 4.3 | 4.3 | 4.3 | -- | Colombia |
| *Cetengraulis mysticetus* | 56.8 | 14.8 | 43.6 | 118.6 | 165.2 | 74.6 | 116.4 | 156.8 | -- | Panamá |
| | 2.1 | -- | -- | -- | -- | -- | -- | -- | -- | México |

1970/1974: Anuario Estadístico de FAO, Vol. 38-1974
1974/1977: Anuario Estadístico de FAO, Vol. 44-1977
1977/1980: Anuario Estadístico de FAO, Vol. 50-1980
1981: Anuario Estadístico de Pesca (SERNAP, Chile)

TABLA 2. RESUMEN DE ESTADISTICAS DE CAPTURA EN EL PACIFICO SUDESTE PARA EL PERIODO 1964 - 1980

(En miles de Toneladas)

| ESPECIE | CAPTURA PROMEDIO | A CAP.- MAX. | B CAP.- MIN. | A/B | A/C.P X |
|---|---|---|---|---|---|
| Anchoveta | 6,219 | 13,059 | 810 | 16* | 2.1 |
| Sardina | 735 | 3,346 | 48 | 70 | 4.5 |
| Machete | 12 | 43 | 2 | 20 | 3.6 |
| Jurel | 291 | 973 | 12 | 81 | 3.3 |
| Caballa | 65 | 284 | 2 | 142 | 4.4 |
| Bonito | 43 | 86 | 4 | 19 | 2.0 |
| Pinchagua | 184 | 616 | 7 | 93 | 3.3 |
| Anchoveta panameña | 69 | 170 | 13 | 13 | 2.5 |

* La relación A/B para la anchoveta sube hasta 210 cuando se considera las capturas inferiores a 100 mil toneladas al iniciar la pesquería a comienzos de la década del 50.

*Engraulis ringens* mostró una abrupta disminución a partir de 1972, en forma mucho más acentuada en la costa peruana (Fig. 1a) mientras que *Sardinops sagax*, comenzó a incrementarse en intensidad similar tanto en Perú como en Chile aunque en una escala 10 veces inferior que la anchoveta (Fig. 1b). Una especie igualmente planctívora como las anteriores, la *Brevoortia maculata*, se mantuvo sin embargo casi permanentemente a niveles bajos en los últimos 17 años; por otro lado, especies también planctívoras por lo menos durante su etapa juvenil, como el *Trachurus s. murphyi* y el *Scomber japonicus*, con una distribución geográfica más amplia que las anteriores, se incrementaron principalmente en Chile (Fig. 1c) después del colapso de la pesquería de anchoveta.

Los cambios de la biomasa de *E. ringens* están ampliamente documentados por los trabajos de IMARPE, resumidos recientemente por Tsukayama 1981 y 1982 (en prensa). Esta información indica un máximo entre 1966-1967 con 23 millones de toneladas aproximadamente, frente a la costa peruana, cuando se capturaba alrededor de 9 millones de toneladas/año y una drástica disminución en 1972-1973 hasta cerca de 3 a 4 millones de toneladas de biomasa.

El incremento notable en las capturas de *S. sagax, T. s. murphyi* y *S. japonicus* al tiempo que la anchoveta colapsó, indican un proceso de cambios en la estructura de las comunidades pelágicas y en la magnitud de sus poblaciones.

La distribución y abundancia de huevos y larvas, corrobora y sustenta estos cambios. EINARSSON y ROJAS DE MENDIOLA (1966) dieron a conocer las altas proporciones de huevos de anchoveta. De un resumen de los trabajos de SANTANDER y DE CASTILLO (1979) y SANTANDER (1980 y 1981) se obtienen los siguientes valores para la costa peruana (porcentaje de anchoveta con respecto a otros peces):

| HUEVOS DE ANCHOVETA% | | Otros Peces |
|---|---|---|
| 1961 a 1964 | 85 | 15% |
| 1965 | 65 | 35% |
| 1966 a 1971 | 80 a 90 | 20 a 10% |
| 1972 | 50 | 50% |
| 1973 | 47 | 53% |
| 1979 | 20 | 80% |

Para la costa de Chile, un resumen de los datos presentados por BRANDHORST et al. (1966 y 1967) muestra lo siguiente:

| | Enero-Febrero 1965 | | Agosto-Octubre 1964 | |
|---|---|---|---|---|
| | Anchoveta | Sardina | Anchoveta | Sardina |
| Nº de estaciones | 393 | 393 | 357 | 357 |
| Nº de estaciones positivas | 43 | 7 | 61 | 32 |
| Nº total de huevos | 2979 | 294 | 24,583 | 1998 |
| % de huevos | 91% | 8.9% | 92% | 7.5% |

Existe mucha mayor información al respecto que probablemente será presentada a esta consulta para un análisis más amplio.

Los trabajos de SANTANDER (1981) muestran un incremento progresivo de huevos de sardina a partir de 1972. La proporción de huevos de sardina antes de 1968 fue insignificante (comunicación personal), aumentando en número y área a partir de 1972, tanto que durante la época reproductiva de 1977, 1978 y 1979 el número de huevos de sardina sobrepasó al de la anchoveta. Se puede ver además, que los índices de co-ocurrencia de los desoves de anchoveta y sardina son cada vez mayores a partir de 1976. Esta situación indica un proceso de sustitución de la anchoveta frente al Perú, por la sardina, con clara tendencia a una colonización cada vez mayor de áreas ocupadas previamente por la anchoveta, tanto en Perú como en Chile.

BERNAL 1983 presenta gráficos que muestran nuevos focos importantes de desove en la zona de Talcahuano y el Golfo de Arauco (35 a 40ºLS). Su tabla II da promedios de huevos de sardina inferiores en 7 a 15 veces, con respecto a la anchoveta, para el período 1964-1973, pero es evidente que después de 1972, el incremento de la sardina viene en notable aumento. El mismo autor encontró una cierta relación inversa en la intensidad del desove de *E. ringens* y *S. sagax* durante los períodos cálidos, con anomalías negativas en el caso de la anchoveta y positivas para la sardina.

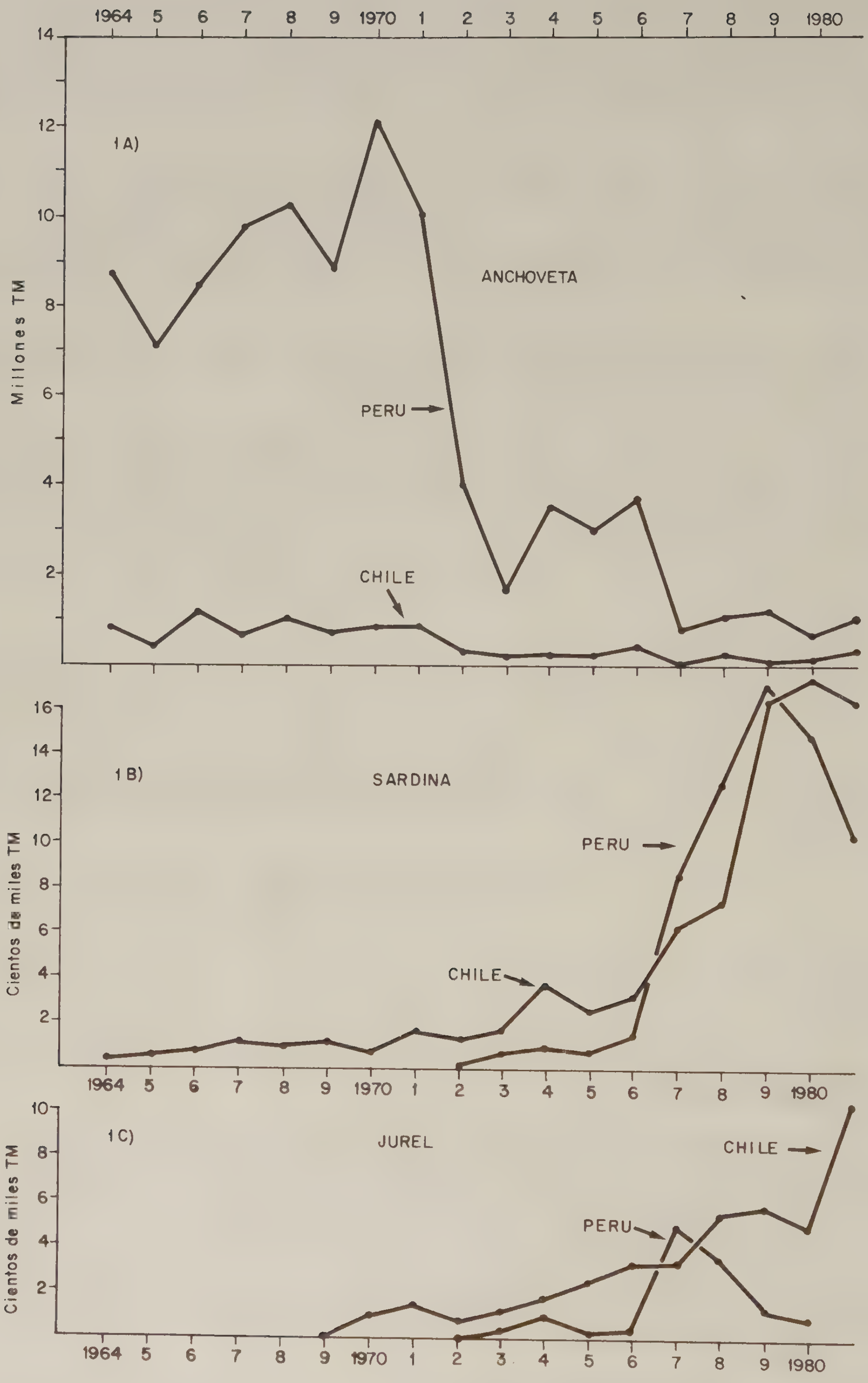

FIGURA 1: Cambios en los niveles anuales de captura.

# VARIABILIDAD DE LAS POBLACIONES DE AVES PRODUCTORAS DE GUANO Y SU RELACION CON LA ANCHOVETA

La existencia del guano, y en consecuencia de las aves que lo producen, se remonta a varios miles de años, lo atestiguan así las grandes acumulaciones de guano coprolífico hallado en las costas del Pacífico Sudeste, principalmente frente al Perú. HUTCHINSON (1950).

Por lo menos durante los últimos 50 años, las principales especies que producen guano comercialmente aprovechable son:

*Phalacrocorax bougainvillii* (Guanay)
*Sula variegata* (Piquero)
*Pelecanus occidentalis thagus* (Alcatraz)

Para épocas anteriores R.C. Murphy (1925), menciona además a *Sulanebouxi* (camanay), aunque reconoce su poco aporte, y a *Pelecanoides garnoti* (potoyunco), cuya importancia pudo haber sido mayor en el pasado. Antonio Raimondi realizó observaciones en 1874 y cita hasta 10 especies, incluyendo aquellas que por su poco número y hábitos de vida fueron seguramente de incidencia residual. No es clara la información sobre si existió cambios en la predominancia de las especies en el pasado. VOGT (1942), GAMARRA (1964) y JORDAN (1966) dieron a conocer sobre la predominancia del guanay con proporciones mayores a 80%, seguidos del piquero 13 a 15% y Alcatraz de 2 a 5%. Para las décadas recientes TOVAR (este volumen) da a conocer la disminución progresiva del guanay, después de El Niño de 1965, llegando a colocarse en proporción inferior al piquero a partir de 1974. En 1979 estos valores fueron: guanay 36%, piquero 53%, alcatraz 11%. La explicación más probable de esta reducción se puede encontrar en los hábitos de pesca de cada especie y en los niveles de abundancia del alimento. Mientras el guanay,de hábitos fuertemente gregarios, pesca regularmente en bandadas compactas sólo durante el día, y requiere principalmente de grandes concentraciones de anchoveta, su principal alimento. El piquero y el alcatraz, tienen una dieta más variada, pescan de día y pueden hacerlo hasta muy tarde o muy temprano aprovechando la luz de la luna y formando bandadas pequeñas o sólo parejas cuando salen a buscar su alimento; en consecuencia requieren sólo de cardúmenes dispersos. Habría que agregar que la capacidad de vuelo de estos es superior a la del guanay.

En cuanto se refiere a la variabilidad númerica, un estudio histórico sobre la fluctuación de las poblaciones de aves (JORDAN y FUENTES, 1966), que abarca 55 años desde 1909 a 1964 sobre la base de la cosecha anual de guano (Fig. 2) y de 1955 a 1966, sobre la base de censos gráficos muestran las grandes fluctuaciones periódicas y sus subsiguientes recuperaciones. La depresión de las poblaciones corresponde casi invariablemente a las ocurrencias de El Niño. Mención especial merece el extraordinario crecimiento en el período 1945-1956, que se debió en primer lugar a la acción del hombre que reacondicionó y amplió las áreas de anidación de las aves, en segundo lugar probablemente a un período de condiciones ambientales favorables, y en tercer lugar a una alta disponibilidad de anchoveta. El grado de predación sobre la anchoveta creció desde valores inferiores a un millón de toneladas/año, en 1942, hasta algo más de 4 millones de toneladas/año en 1955, para una población de 28 millones de aves adultas.

Con el fin de analizar las relaciones de la fluctuación de las aves, la pesca y las ocurrencias de El Niño, presentado por JORDAN y FUENTES (1966), en su Gráfico 2, se han actualizado los valores desde 1955 hasta 1980, en base a las informaciones obtenidas por el Departamento de Aves de IMARPE (Fig. 3). La disminución de las aves en El Niño de 1965 y su falta de recuperación en los próximos 15 años es un aspecto que debe analizarse en mayor detalle.

Llegado aquí, vale la pena examinar el tipo de relación establecida entre las aves y la anchoveta. VOGT (1942) expone con claridad la importancia determinante de la anchoveta para la supervivencia de las aves y desarrollo de sus poblaciones. Por otro lado, al analizar contenidos estomacales se encontró que el 96% de la dieta del guanay estuvo constituída por anchoveta, cerca de un 80% para el piquero y el alcatraz. En épocas de escasez y desnutrición la dieta puede ser mucho más amplia. Es probable que en las actuales circunstancias de bajos niveles de biomasa de anchoveta e incremento de otros, las aves estén en un proceso de readaptación a las nuevas condiciones.

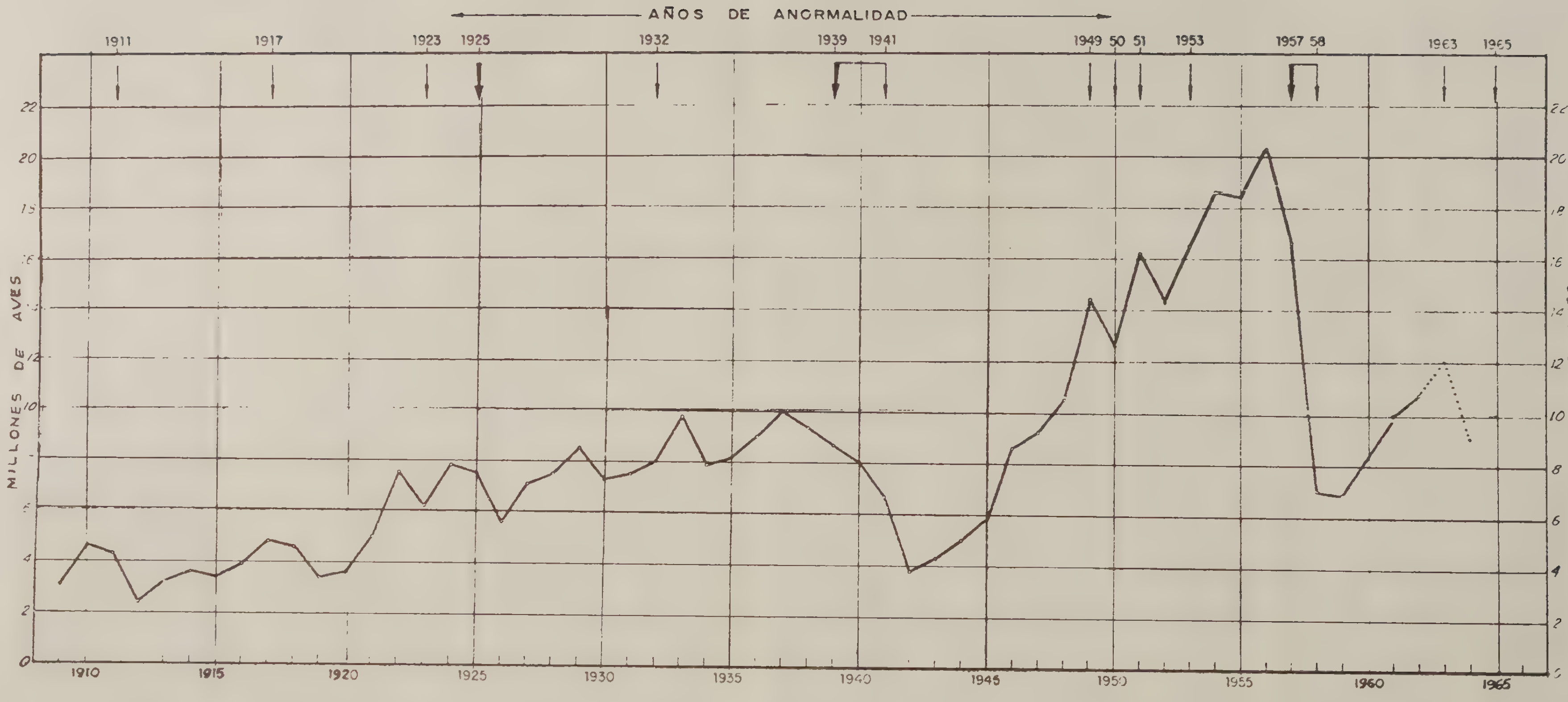

FIGURA 2: Flųctuación dę las poblaciones de aves, en base a la cosecha anual de guano 1909 - 1964
De JORDAN y FUENTES (1966).

En los años pasados esta dependencia de la anchoveta se reflejaba inclusive en reacciones fisiológicas y de comportamiento de las aves, con una pesca diaria más frecuente y una reproducción reiterada en presencia de abundante anchoveta cerca de las islas; o abandono de sus huevos y polluelos cuando se producía una disminución persistente de alimentos, como ha ocurrido invariablemente durante la presencia de El Niño relación que aparece ampliamente documentada en los Boletines de la Compañía Administradora del Guano y en los del Instituto del Mar.

Lo que hasta ahora se sabe es que la anchoveta adulta, durante El Niño, cuando las temperaturas son muy superiores al promedio y el alimento escaso, se desplaza a áreas más favorables. Esta perturbación oceánica puede, asimismo, interrumpir el proceso reproductivo o disminuirlo y producir mortandad de larvas. Tal situación genera una disminución temporal de alimento para las aves, obligándoles a realizar grandes "migraciones" con una alta mortandad en el trayecto. Por otro lado es conocido el incremento de la pesquería de anchoveta, a partir de los años 50 y la disminución de sus principales predadores, las aves guaneras y el bonito, situación que resulta de gran importancia ecológica.

Esta interrelación entre la anchoveta planctófaga, las aves predadoras, el ambiente y la pesquería, nos permite algunas deducciones sobre la variabilidad de las poblaciones y su conexión con la pesca de anchoveta.

Los aspectos más fundamentales pueden resumirse como sigue: a) Antes de la pesca intensiva de anchoveta, las poblaciones de aves deprimidas por los fenómenos de El Niño, se recuperaban en los próximos años; b) Los cuatro años siguientes a El Niño 1957/58 son de continua recuperación, hasta alcanzar 18 millones de aves en 1963, no obstante que la pesca se incrementó considerablemente en ese período, desde cerca de 2 millones de toneladas en 1959 hasta cerca de 7 millones en 1963; c) El siguiente Niño de 1965 deprimió una vez más a las aves hasta niveles de 4 millones, pero del que ya no fueron capaces de recuperarse en los siguientes 15 años, mientras la pesca logró superar inclusive los 12 millones de toneladas de captura en un año (1970); d) El Niño de 1972/73 deprime a las aves hasta menos de 2 millones, pero es la pesquería esta vez, la que experimenta su caída más espectacular, hasta cerca de dos millones de toneladas, trayendo consigo el colapso de la pesquería; e) La gran caída de la pesca de anchoveta a partir de 1972 guarda estrecha concordancia con la declinación de la biomasa reportada por varios trabajos, el más reciente de TSUKAYAMA 1982); f) Desde fines de los años 60 las poblaciones de aves han venido soportando una doble presión, El Niño que las deprime, actuando como un mecanismo de autrocontrol del ecosistema, mientras el stock de anchoveta se mantiene alto, y otro generado por el hombre, al competir con ventaja y disminuir considerablemente la biomasa de anchoveta. Probablemente a partir de aproximadamente 1966, la pesquería ya estuvo tomando parte de los peces que dejaron de capturar las aves; g) La respuesta instantánea de las poblaciones de aves frente a la ocurrencia de El Niño y su dependencia de la anchoveta, las indican como especies muy sensitivas a las variaciones de la distribución y abundancia de sus fuentes de alimentación, y con reacciones de fácil observación (reproducciones fallidas, migraciones, mortandad).

## NATURALEZA DE LOS CAMBIOS DE ABUNDANCIA Y COMPOSICION POR ESPECIES, A PARTIR DE EL NIÑO DE 1972/73

No existen al parecer dudas en la literatura, en el sentido de que los grandes y abruptos cambios de las poblaciones de aves marinas, en el Pacífico Sureste, desde épocas pasadas se han debido a la influencia del fenómeno de El Niño que disminuye sus fuentes de alimentación. Se deduce igualmente que las poblaciones de peces pelágicas como la anchoveta, sustento de las aves, fluctúan igualmente por la misma causa con una disminución temporal de la accesibilidad a las aves y restitución a la normalidad concluido El Niño. Estas pulsaciones del ecosistema de afloramiento costero, se producen, según se sabe, con influencia marcada en las comunidades planctónicas y en los niveles tróficos superiores. El impacto observado es de tal naturaleza que disloca los enlaces ecológicos, produciendo cambios notables en la fisiología de la reproducción, disminución de la supervivencia de huevos y larvas de anchoveta y mortandades masivas en las poblaciones de aves. A pesar de ello, en ninguno de los Niños estudiados por diferentes autores se registraron cambios más o menos persistentes en la estructuta de las especies y en la abundancia, sin embargo, no se descarta que algunos Niños catastróficos hayan producido en el pasado cambios más persistentes como el que sugiere DE VRIES (1979, citado por Mathisen, 1979).

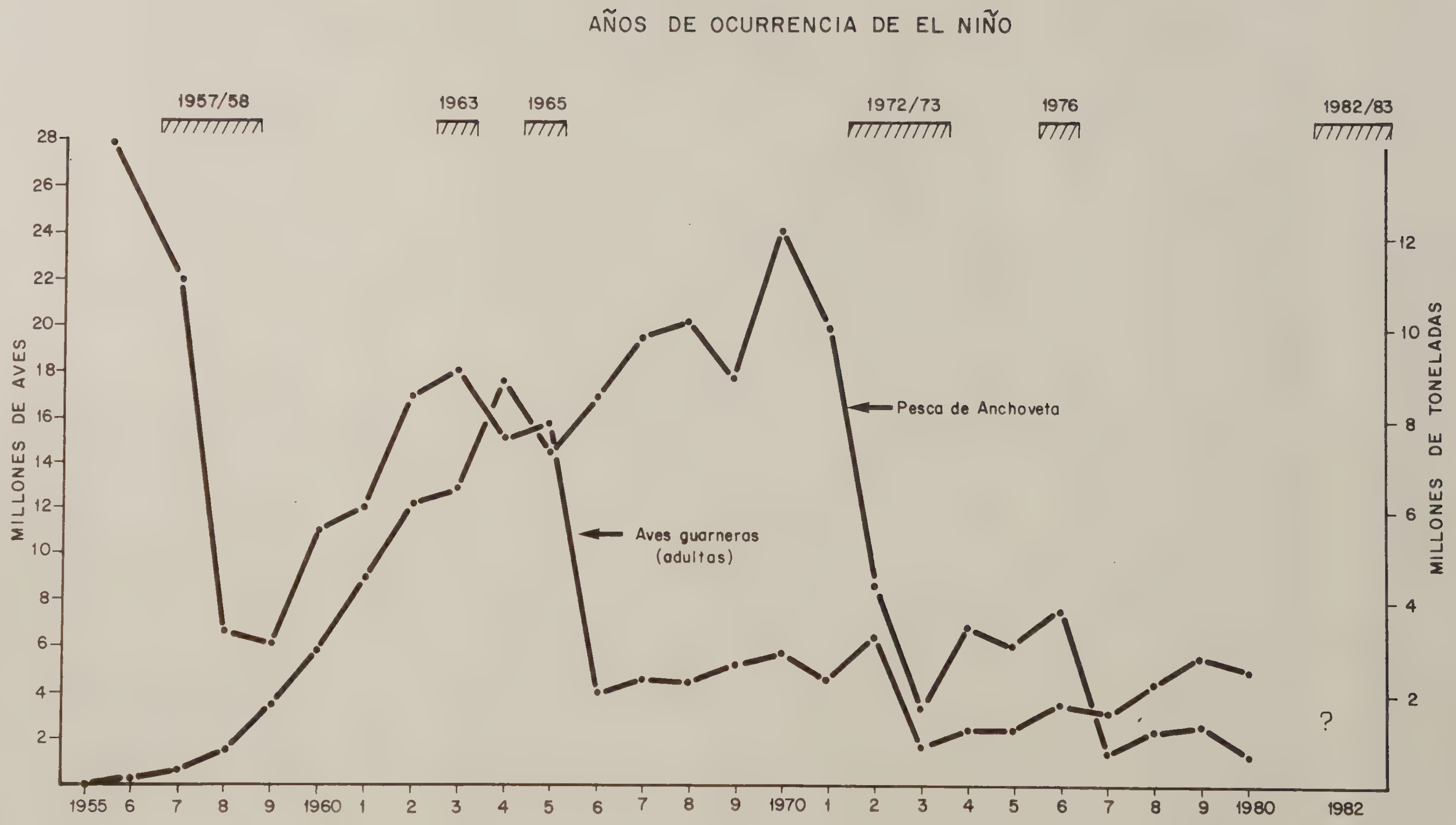

FIGURA 3. Fluctuaciones de las poblaciones de aves en base a censos gráficos, cambios de los volúmenes de captura de anchoveta y años de ocurrencia de El Niño.

El Niño de 1972/73 marca el inicio de cambios profundos tanto desde el punto de vista de la biomasa de las poblaciones como de la composición de las especies. En este caso tal como se discutirá posteriormente con mayor detalle, no fue El Niño el único responsable sino la pesca intensa. Para resumir los cambios cuantitativos y cualitativos así como el efecto de cada uno de los factores mencionados, El Niño y la pesca, podemos examinar en primer lugar la Fig. 4, junto con las anteriores ya comentadas. En esta figura se presenta algunos de los cambios más significativos ocurridos en la costa peruana y habría que añadir los del *Trachurus symmetricus murphyi* (jurel) y *Scomber japonicus peruanus* (caballa), similares en su tendencia general con la sardina, comentado anteriormente (Tablas 1 y 2).

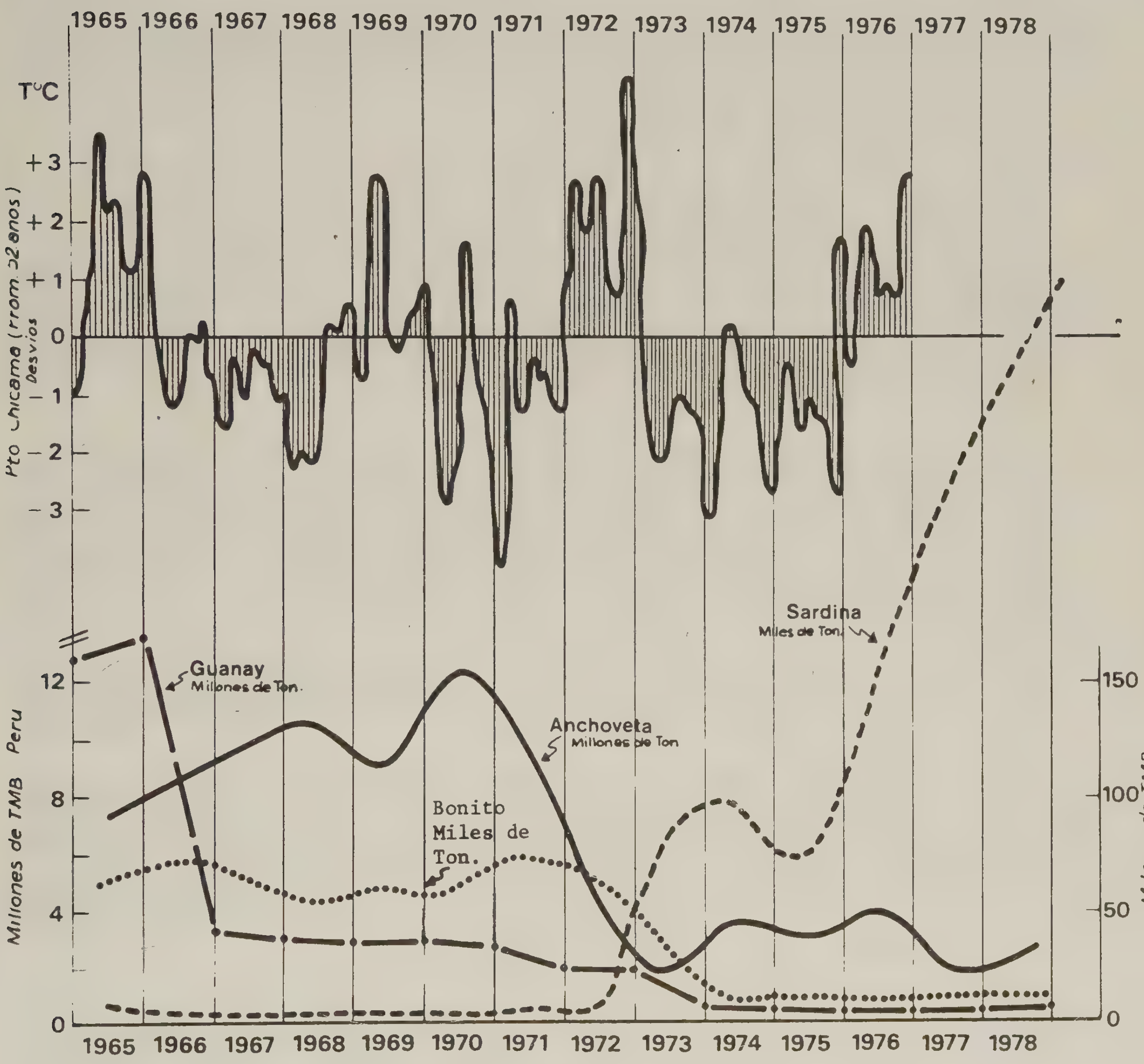

FIGURA 4: Cambios en la composición de especies y su relación con la pesca y El Niño.

Al analizar los posibles efectos de la pesquería de anchoveta en los cambios obervados, se puede considerar los siguientes elementos básicos:

- A fines de la década del 60 y principios del 70, la captura cada vez más alta de peces padres y hasta el 80% de reclutas, con un máximo rendimiento sostenido de 9.5 millones anuales, que al parecer era demasiado alto y frecuentemente sobrepasado en la práctica, puso al recurso en una situación sumamente inestable, como lo reconoce IMARPE en sus informes. Así, la renovación de la población cada año, sólo dependía de exitosos reclutamientos, consecuencia en gran medida de condiciones del ambiente favorables; de tal manera que una falla en el reclutamiento acarrearía una perturbación profunda en el stock.

- Al presentarse El Niño de 1972/73, uno de los más severos, descendieron los desoves, se perdió todo un reclutamiento y los adultos remanentes, fueron pescados en proporciones muy altas y en tiempo corto conduciéndoles hasta niveles inferiores al promedio de desovantes requerido para la recuperación anual, calculado por CSIRKE (1979) en 4 millones de toneladas de padres.

- Una disminución desde 20 a 30 millones de toneladas de biomasa de anchoveta a tan sólo 3 millones en el lapso de unos 10 años de pesca intensa, creó finalmente en el ecosistema de afloramiento un vacío ecológico. Al disminuir el consumo de plancton y relajarse la presión de competencia sobre especies afines planctívoras, se activó su expansión. Este fue el caso de la sardina, jurel y caballa. Pero al mismo tiempo, la disminución drástica de la biomasa de anchoveta afectó desfavorablemente a las especies predadoras como las aves guaneras y el bonito. Dadas las relacione tróficas de la anchoveta con la mayoría de especies predadoras de la región nerítica, tanto pelágicas como demersales, es muy probable que estén ocurriendo cambios notables en toda la estructura de las comunidades del ecosistema costero.

- En esta forma creemos que si bien la pesca intensa está en el fondo del problema de las declinaciones de población, El Niño de 1972/73 actuó como un disparador para un nuevo ordenamiento en la estructura de especies. En momentos de escribir esta nota, estamos asistiendo a la ocurrencia del fenómeno de El Niño 1982/83, uno de los más intensos, el cual probablemente deprimirá aún más al stock de anchoveta y a las poblaciones de aves guaneras. En los últimos años la anchoveta no sólo ha tenido que soportar la competencia con la sardina en proceso de expansión, y de otras especies, sino la predación de sus huevos y larvas, y la pesca.

  Durante la Tercera Reunión del Comité Científico de ERFEN fue comunicada la presencia frente a las costas del Perú de grandes concentraciones de celenterados pelágicos en 1972 y 1973, lo que pudiera indicar cambios aún más profundos en el ecosistema pelágico (comunicación personal de J. Valdivia).

Por todo lo discutido previamente y teniendo en cuanta que El Niño 1972/73 no puede ser considerado de efectos más intensos que los de 1939/41 y los de 1957/58, años en los que no se presentaron cambios en la composición de especies. Se puede asumir que la pesca intensa jugó un rol importante en los cambios que se vienen registrando en la comunidad pelágica nerítica durante 11 años consecutivos a partir de 1972 y con tendencia hacia una mayor profundización de la preponderancia de la sardina, el jurel y la caballa sobre la anchoveta, los cambios en la abundancia y orden de preponderancia de las aves guaneras, y tal vez, otro tipo de cambios en los niveles inferiores.

Es importante señalar que estas modificaciones en la composición de especies en el Pacífico Sudeste, se desarrollan con características diferentes frente al Perú y frente a Chile, por lo menos, en cuanto se refiere a los peces pelágicos. Mientras la anchoveta mantuvo tradicionalmente sus más altos niveles de biomasa y sus centros de reproducción en el Perú, concordante con los focos principales de anidación de las aves (desde la isla Lobos de Afuera a Punta Coles, cerca de la frontera con Chile), en Chile las magnitudes de biomasa de anchoveta se consideraron aproximadamente 1/10 de las de Perú, lo que al parecer está confirmado también por los máximos de captura que en Perú alcanzaron los 12 millones de toneladas y en Chile alrededor de un millón (Fig. 1) así como por los claramente diferentes niveles de magnitud de huevos y larvas en el plancton.

Desde el punto de vista del impacto en el ecosistema de afloramiento, una disminución de aproximadamente 8 a 9 millones de toneladas de biomasa en el segundo nivel trófico, significó la liberación unas 10 veces mayor de materia orgánica no utilizada, en el primer nivel trófico, creando una condición favorable para la expansión de otras especies filtradoras. WALSH (1981) , calcula los cambios en el flujo de carbón en los diferentes niveles mostrando una disminución en la cantidad de carbón disponible para la cosecha por el hombre desde 60.05 (60 para la anchoveta y 0.05 para demersales) a sólo 6.71 (2.00 para anchoveta, 4 para sardina y 0.71 para demersales).

Se puede suponer que en la costa chilena este impacto debió haber sido mucho menor, precisamente por la menor biomasa de anchoveta perdida. Sin embargo, es interesante anotar que, mientras en Perú la caída de la pesca fue por un factor de 15, en Chile este fue de 57 como se puede ver; aunque en el caso de las capturas de Chile debe considerarse el hecho de que la flota de anchoveta se transformó temprano a la de sardina.

| CAPTURAS x $10^3$ | PERU | CHILE |
|---|---|---|
| Máxima | 12,277 (1970) | 1,091 (1966) |
| Mínima | 792 (1977) | 19 (1977) |
| Máx./Mín. | 15.5 | 57.4 |

Por las características anotadas anteriormente, mientras en el Perú se puede hablar de una sustitución de la anchoveta por otras especies y una "restitución parcial" de la biomasa de anchoveta perdida, por el incremento de sardina, jurel, caballa y probablemente otras especies; en el caso de Chile bien podría hablarse de una "activación " del ecosistema con aumento de la producción en el nivel trófico secundario.

## CONCLUSIONES

Se presentan cambios importantes de biomasa y composición de especies pelágicas en el Pacífico Sureste, asociadas al fenómeno de El Niño y a la pesca intensa desde 1972. Estos cambios se refieren a la disminución muy pronunciada de anchoveta *Engraulis ringens* hasta cerca de 1/10 de su biomasa original y al incremento de la pesca de sardina *Sardinops sagax* unas 70 veces, jurel *Trachurus symmetricus murphyi* cerca de 81 veces y caballa *Scomber japonicus* más de 100 veces. El aumento del número de huevos de sardina en el plancton desde 1972, sustenta el incremento de biomasa y la expansión de nuevas y más extensas áreas de sardina. Paralelamente el guanay *Phalacrocorax bougainvillii* predador de la anchoveta ha cedido su preponderancia a otra especie bajando desde 80% al 38% y otro predador, el bonito *Sarda sarda chiliensis* descendió sus capturas a niveles muy bajos.

Se postula que siendo El Niño un elemento de perturbación temporal que se produce desde épocas remotas, no es la causa determinante de cambios tan profundos en la composición de especies, ni de la drástica disminución del stock de anchoveta. Probablemente, al Niño de 1972/73 puede considerársele como un factor concurrente actuando como un "disparador" en momentos en que la población de anchoveta llegó a niveles de peligrosa inestabilidad y disminución progresiva de la biomasa, como consecuencia de la pesca muy intensa.

La violenta disminución de la anchoveta dejó libre en el ecosistema una cantidad considerable de materia orgánica en el primer nivel trófico, por lo menos en una cantidad equivalente a 10 veces la biomasa de anchoveta de los años 60, lo que trajo consigo paralelamente un relajamiento de la tensión de competencia sobre otras especies planctívoras que iniciaron su expansión. En este caso un elemento concurrente y no determinante serían las condiciones oceanográficas favorables para las nuevas especies.

Las investigaciones de sedimentos marinos que mostraron para el pasado una predominancia preponderante de la anchoveta frente a otras especies neríticas en la costa peruana en una proporción del 79%, es una situación diferente a la actual, en que la sardina tiende a equiparar o aún superar la biomasa de anchoveta; siendo en la costa chilena de hecho superior.

La población de anchoveta disminuida, está actualmente sometida a tensiones incrementadas como consecuencia de una competencia de especies en plena expansión, que antes estuvieron denominados; una predación mucho mayor que antes, sobre todo al nivel de huevos y larvas, y probablemente mayor canibalismo, como consecuencia de una densidad incrementada.

La variación en la preponderancia de las especies se ha presentado bajo características diferentes en las costas de Perú y Chile. Mientras en Perú, esta semeja un proceso de sustitución de especies con pérdida notable de biomasa de la anchoveta, anteriormente preponderante, y una parcial restitución de esa biomasa perdida, por la sardina, jurel y caballa; en Chile, la impresión es el de una activación del ecosistema con una producción comparativamente más alta que antes, en el segundo y tercer nivel trófico.

La ocurrencia actual de El Niño 1982/1983 puede coadyuvar a que se intensifiquen los cambios en la composición de especies y de biomasa en la dirección de una mayor preponderancia de sardina, jurel y caballa, que al parecer vienen compartiendo favorablemente la productividad primaria y secundaria.

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*SOUTH EAST PACIFIC - PACÍFICO SUDORIENTAL*

# VARIABILIDAD DE LAS CONDICIONES OCEANOGRAFICAS EN EL AREA DEL FRENTE ECUATORIAL

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## Summary

Study of the oceanographic information and plankton materials of various expeditions and scientific investigations off Ecuador permitted evaluation of the variability of oceanographic conditions and of the plankton, according to patterns of geographic distribution and related to specific hydrographic characteristics.

Special emphasis was given to the hydrographic conditions of the Equatorial Front, and also to the distributions of primary production, phytoplankton and zooplankton in oceanic and Ecuadorian coastal waters.

The principal components of phytoplankton and zooplankton associated with the Equatorial Front were studied, as were the changes in the plankton population when atypical conditions such as El Niño were recorded.

# INTRODUCCION

Tradicionalmente los frentes marinos han sido identificados por los pescadores como bandas angostas en la superficie del mar, con olas peculiares u ondulaciones características que presentan comúnmente agregaciones de material flotante.

Las zonas frontales corresponden al área de estratificación horizontal producida por el encuentro de dos masas de agua de propiedades distintas, que originan una turbulencia geofísica que juegan un rol fundamental en la dinámica de los océanos. En los frentes existen regiones de convergencia y de movimientos verticales de relativa intensidad que dan lugar a divergencias.

La circulación frontal puede desarrollar un mecanismo que genere una continua energía a pequeña y gran escala. Ciertas características de los frentes, están señaladas por singularidades en el gradiente horizontal de la temperatura, salinidad, densidad, velocidad de las corrientes, clorofila, etc. Su localización está definida por la presencia de una particularidad como es el máximo gradiente horizontal de las características arriba indicadas.

Los sistemas frontales comparten propiedades comunes de persistencia, que fluctúan de horas a meses, a pesar de la difusión de las propiedades a través de los fuertes gradientes horizontales, y de la convergencia superficial asociada a una fuerte convección vertical, que usualmente es de un orden de magnitud mayor que la convección vertical del océano abierto.

Se sabe desde hace mucho tiempo que el encuentro a la escala geográfica de una masa de agua fría y rica, y una masa de agua caliente y más pobre en nutrientes y organismos se traduce por un aumento de la productividad de la biomasa en la vecindad del frente. El hecho es bien conocido por los pescadores, que suelen buscar zonas de frente, donde encuentran usualmente concentraciones de atunes, cetáceos, etc. superiores al promedio. Algunos autores describen el aumento de biomasa planctónica a nivel de un frente, sin que haya ningún afloramiento, estableciendo que la biomasa de zooplancton a la del fitoplancton es más importante del lado de las aguas más pobres.

Varias teorías han sido propuestas para explicar el enriquecimiento frontal. Griffith (1965), por ejemplo, menciona causas fundamentales de esta alta productividad a la acumulación mecánica de plancton a nivel de una convergencia, o una producción a partir de nutrientes llevados a nivel de una divergencia. En el primer caso es posible que exista una eutroficación local por acumulación y hundimiento de materia orgánica y posteriormente de nutrientes, y en el segundo caso, una producción nueva.

Uda (1959) sugiere que los frentes actúan como zonas limítrofes de distribución de organismos (vegetales y animales) en una manera similar a delimitaciones zoogeográficas. También ha señalado que las zonas de convergencia frontales determinan la localización de acumulaciones de plancton y material en suspensión que a su vez determinan las agregaciones de otros organismos de la cadena alimentaria, como peces. Esta observación es explotada al máximo por los pescadores japoneses. Uda (1959) también sugiere que en adición al efecto acumulativo de dos masas de agua convergentes, los frentes tienen un efecto estimulativo en el crecimiento del fitoplancton.

Dufour y Stretta (1973), Stretta, Noel y Vercesi (1975) han determinado que a la altura de la costa oeste africana, la riqueza en fitoplancton y zooplancton es tres veces más importante del lado de las aguas frías que el de las aguas calientes del frente. Sin embargo, en este caso, la biomasa explotada de atunes se relaciona al ecosistema del límite de las aguas cálidas. En la época de aparición del frente, se concentra en la vencidad de éste, explotando la biomasa pelágica mantenida en un alto nivel, gracias al contacto de los dos ecosistemas. Similares hallazgos han sido observados en el Pacífico en relación a los atunes (Blackburn,1965).

Frente Ecuatorial

Wooster (1969), menciona como posición promedio del Frente Ecuatorial los 80° y 90°W, entre las costas de Ecuador y lasIslas Galápagos y expresa que el frente es una manifestación superficial que se caracteriza por ser una región que separa las aguas frías y más salinas pertenecientes a la Corriente Humboldt, de las cálidas y menos salinas procedentes del Norte. El límite de ambas es el Frente Ecuatorial. Las variaciones de posición de este frente en el espacio y el tiempo son notorias a través del año. También las determinaciones de las corrientes superficiales (Observaciones del EASTROPIC) muestran que las aguas del frente son convergentes. Dicha convergencia es el resultado del sistema de circulación oceánica al Norte y Sur del frente. Wooster (1969), mediante el análisis de los promedios de la temperatura superficial mensual, definió algunas características generales del frente que son las siguientes: 1. El frente Ecuatorial es una característica superficial confinada sobre los 100 metros de profundidad; 2. Es una característica permanente; 3. La localización del frente varía estacionalmente; 4. El frente está orientado zonalmente (Oeste-Este) entre las Galápagos y los 84°W, y meridionalmente (Noreste-Sureste) al Este de los 83°W; y 5. El gradiente de temperatura a través del frente, decrece de Este a Oeste, y tendiendo en el hemisferio sur a ser mayor, durante el invierno, que durante el verano.

Posteriormente, las investigaciones de Pak y Zaneveld (1974) han contribuido principalmente al conocimiento de las características oceanográficas ligadas al Frente Ecuatorial. Estas fueron realizadas en el crucero del R/V "Yanquina", en Octubre y Diciembre de 1971, en el área comprendida desde el Oeste de las Islas Galápagos hasta las proximidades de las costas del Ecuador.

La contribución principal del estudio de Pak y Zaneveld (1974) son las evidencias que presentan dichos autores con respecto al aporte de agua fría al frente tanto de la Corriente de Humboldt como del Afloramiento Ecuatorial (relacionado con la Subcorriente Ecuatorial). Debido a las grandes variaciones estacionales de la Corriente de Humboldt, en su velocidad y temperatura, es de esperarse que la contribución de esta corriente al Frente Ecuatorial, muestre también una correspondiente variación estacional. En base a esta indicación, los autores han concluido que el Afloramiento Ecuatorial contribuye en forma permanente el aporte de agua fría al frente, mientras que la corriente de Humboldt presenta una contribución estacional al Frente Ecuatorial en la región entre la costa del Perú y las Islas Galápagos.

Debido a la importancia que tiene el trabajo de Pak y Zaneveld (1974) para las futuras investigaciones de la oceanografía física y biológica del Frente Ecuatorial, nos permitimos presentar las conclusiones a que han llegado estos autores: 1.- El afloramiento ecuatorial asociado con la divergencia inducida por el viento y la Subcorriente Ecuatorial, parece ser el mayor origen del agua fría del frente ecuatorial al Oeste de las Islas Galápagos; 2.- La subcorriente Ecuatorial se extiende al Este de las Islas Galápagos más allá de los 85°30°W, (Pak y Zaneveld, 1973) encontrándose así la subcorriente asociada con el afloramiento al lado Este de las Islas Galápagos; 3.- Se observa que un Frente Ecuatorial bien definido está asociado con el afloramiento ecuatorial al Este de las Islas Galápagos; 4.- Sugieren los autores que en adición a la Corriente de Humboldt, el afloramiento asociado con la Subcorriente puede ser el mayor origen del agua fría del Frente Ecuatorial en la región situada el Este de las Islas Galápagos entre los 3°N y 3°S.

Enfield (1976) recientemente ha resumido la información existente sobre las características hidrográficas del Frente Ecuatorial, así como la relación del Frente con la circulación termohalina, ligada a las condiciones anómalas de "El Niño".

En cuanto a los aspectos biológicos del área, la mayor cantidad de datos existentes se refiere a las concentraciones de clorofila, mediciones de la producción primaria y volúmenes de zooplancton. La mayor parte de estos trabajos se basan en datos aislados de estos parámetros, con relación a algunas estaciones localizadas en el área del Frente Ecuatorial, pero sin describir las variaciones de los parámetros biológicos dentro del área ecuatorial. Caben citarse dentro de estos trabajos las investigaciones de: Holmes, Shaefer y Shimada (1957), Forsbergh y Joseph (1964), Owen y Zeitschell (1970) y Chin (1970).

En los últimos años, es el trabajo de Miró, Jiménez, Gualancañay y Luzuriaga (1974), el que mejor resume las condiciones de la biomasa fitoplanctónica, expresada en concentraciones de clorofila *a* y, de la producción primaria, en mg. C/m$^3$/hora, en superficie, con respecto al Frente Ecuatorial. Posteriormente en los trabajos de Jiménez (1976) y Jiménez y Pesantes (1978) se analizan el fitoplancton y la producción primaria de toda la zona eufótica de las aguas costeras del Ecuador mientras el Frente estuvo presente.

En lo que respecta al zooplancton, la información existente es escasa encontrándose datos aislados de biomasa zooplanctónica en los trabajos de Holmes, Shaefer y Shimada (1957) y Forsbergh y Jospeh (1964). En las investigaciones recientes, las mayores contribuciones se encuentran en los trabajos sobre foraminíferos plantónicos de Miró y Luzuriaga (1974), Luzuriaga de Cruz (1976), sobre eufaúsidos; en las investigaciones de Cornejo de González (1976) y Antezana y González (1979) y, sobre la biomasa y distribución de plancton del Frente Ecuatorial en las publicaciones de Jiménez (1979) y Jiménez y Bonilla (1980).

A pesar de la información existente, no ha podido integrarse en un todo orgánico de tal modo que permita interpretar la variabilidad de la producción planctónica en relación a las variaciones del frente a través de los años o en relación a la presencia de condiciones anómalas como el fenómeno El Niño.

Los gradientes de temperatura y salinidad a través del Frente Ecuatorial son de estructura compleja y pueden variar hasta 6°C y $2^{o}/oo$, respectivamente en una distancia de hasta 30 millas. Aunque la exacta localización física del frente puede variar en decenas de millas por un período de días o semanas, su posición promedio aparece perpendicular, oblicuo o pararelo a la costa, en los distintos meses del año o de un año a otro, presentándose los gradientes térmico-salinos más acentuados al sur de la costa de Ecuador. En estas áreas se concentra el mayor esfuerzo pesquero de la flota pesquera pelágica ecuatoriana, a través de todo el año, confirmando este hecho el alto significado de las propiedades biológicas de esta área.

El presente trabajo intenta describir las características más relevantes que caracterizan al Frente Ecuatorial, en relación a los máximos de biomasa de fitoplancton y zooplancton registrados en varios meses del año y durante el período comprendido entre 1972 a 1983. También se incluyen determinadas épocas, cuando las condiciones oceanográficas no permiten el desarrollo del Frente, tal como ocurre con la incursión de aguas cálidas y asociadas al fenómeno El Niño.

Uno de los objetivos de este trabajo es mostrar como las concentraciones de fitoplancton (expresadas en valores $>$0.5 mg/m$^3$ de clorofila *a* y de zooplancton en valores $>$1000 ml/1000 m$^3$) pueden presentar considerables variaciones a través del tiempo y del espacio, lo que podría repercutir en la supervivencia de las larvas de las especies pelágicas.

## METODOS

Los datos analizados provienen de 15 cruceros realizados a bordo del BAE "ORION" del Instituto Oceanográfico de la Armada del Ecuador y de los B/I "Huayaipe" y B/I "Tohallí" del Instituto Nacional de Pesca, durante el período de 1972-1983. El presente trabajo incluye información de algunos cientos de datos de temperatura y salinidad, así como el procesamiento de cientos de muestras para análisis de clorofila *a* y determinación de volúmenes de zooplancton. En la Tabla 1 se mencionan los cruceros realizados, así como los datos de clorofila *a* y zooplancton que estuvieron disponibles para este trabajo. La mayor parte de la información de estos cruceros ha sido publicado en mayor detalle por los Institutos del Ecuador previamente mencionados en revistas e informes de distribución interna. Una mejor información de las metodologías utilizadas se encuentra en el trabajo de Jiménez y Bonilla (1980).

TABLA 1.-CRUCEROS REALIZADOS EN ECUADOR ENTRE 1972 Y 1983, QUE SON INCLUIDOS EN EL ANALISIS DE ESTE TRABAJO

| CRUCERO | FECHA | $T^{\circ}C$ | $S^{\circ}/oo$ | Clorofila *a* | Zooplancton |
|---|---|---|---|---|---|
| BAE "ORION" | Agosto-Septiembre 1972 | x | x | - | - |
| BAE "ORION" | Diciembre, 1972 | x | x | + | - |
| BAE "ORION" | Mayo, 1973 | x | x | x | x |
| BAE "ORION" | Septiembre, 1974 | x | x | x | x |
| BAE "ORION" | Diciembre, 1974 | x | x | - | - |
| R/V "MOANA WAVE" | Febrero-Marzo, 1975 | x | x | x | x |
| B/I "HUAYAIPE" | Septiembre-Octubre, 1975 | x | x | x | x |
| BAE "ORION" | Marzo-Abril, 1976 | x | x | x | x |
| BAE "ORION" | Junio-Julio, 1978 | x | x | x | x |
| BAE "ORION" | Marzo,1979 | x | x | - | - |
| B/I "TOHALLI" | Julio, 1980 | x | x | x | ? |
| B/I "TOHALLI" | Febrero-Marzo, 1981 | x | x | x | ? |
| B/I "TOHALLI" | Agosto, 1981 | x | x | x | ? |
| B/I "TOHALLI" | Noviembre-Diciembre, 1982 | x | x | x | ? |
| B/I "TOHALLI" | Enero, 1983 | x | x | x | ? |

x = datos disponibles
- = datos no disponibles
+ = datos deducidos contajes fitoplancton

## RESULTADOS

A continuación trataremos de resumir la información que fue más relevante tanto desde el punto de vista oceanográfico como biológico en aguas ecuatorianas, a través de los meses y años que se hace referencia en este trabajo y cuyos datos fueron accesibles al autor.

En Agosto-Septiembre de 1972 (Fig. 1) el Frente Ecuatorial se encontraba desarrollado aunque se observó en forma anticipada un incremento de la temperatura en la zona norte del Ecuador. Igualmente no fue tan marcado el gradiente térmico salino que caracteriza usualmente al frente, con un mayor espaciamiento de las isotermas, y con una posición bastante perpendicular con respecto a la costa. En Diciembre de 1972 (Fig.2) las condiciones que tipifican al frente habían desaparecido, registrándose la incursión de aguas cálidas procedentes del noroeste con temperaturas entre $26^{\circ}C$ y $27^{\circ}C$, características de las condiciones atípicas de el fenómeno El Niño. El predominio de los dinoflagelados desde el océano abierto hacia la costa, estuvo asociado con el fenómeno, encontrándose solamente pequeños parches de diatomeas circunscritos al norte del Ecuador y en las vecindades de la costa (Pesantes, 1980). Con respecto al zooplancton, se observó el predominio de organismos típicos de aguas cálidas, como los foraminíferos planctónicos encontrándose (las especies que caracterizan a las aguas más frías en las inmediaciones de la costa y en las aguas del Golfo de Guayaquil (Luzuriaga de Cruz, 1976)).

En Mayo de 1973 (Fig. 3), el frente se encontró bastante desarrollado, con una posición Noroeste-Sureste, y un fuerte gradiente termohalino, caracterizado por temperaturas de $20^{\circ}C$ al sur y $26^{\circ}C$ al Noreste. El gradiente más fuerte fue encontrado al Sur, donde se localizaron las aguas más frías procedentes de la Corriente de Humboldt. El gradiente al Noroeste, posiblemente este último estaba asociado a la extensión de la Subcorriente Ecuatorial, que emerge en la superficie, originando una alta productividad en todo el límite sur del frente (Jiménez, 1978). En tal ocasión se presentó en esta área una alta concentración de fitoplancton tanto en las aguas costeras como en las oceánicas, observándose que la capa de mezcla estuvo cerca de los 10 m de profundidad. El fitoplancton predominante estuvo constituido por diatomeas de gran tamaño como *Rhizosolenia alata, Rhizosolenia styliformis var. oceánica, Thalassiotrix heteromorpha* y especies de *Thalassiosira*.

Los volúmenes más altos de zooplancton se registraron en el margen septentrional del frente, donde se produce la divergencia con temperaturas superficiales superiores a $24^{\circ}C$. Además se notó un desplazamiento de estas altas concentraciones de zooplancton hacia la costa, produciéndose un segundo máximo de zooplancton, en el sur, a la altura del Golfo de Guayaquil, en el área donde se acentúa el gradiente termohalino. Las mayores concentraciones de zooplancton en estas áreas estuvieron caracterizadas por el predominio de copépodos, en concentraciones 3 veces mayor que en el límite sur del frente. Posiblemente este hecho estuvo relacionado a una convergencia en el límite de las aguas cálidas del frente. También se encontraron en cantidades considerables los Quetognatos y Pterópodos (Jiménez, 1978).

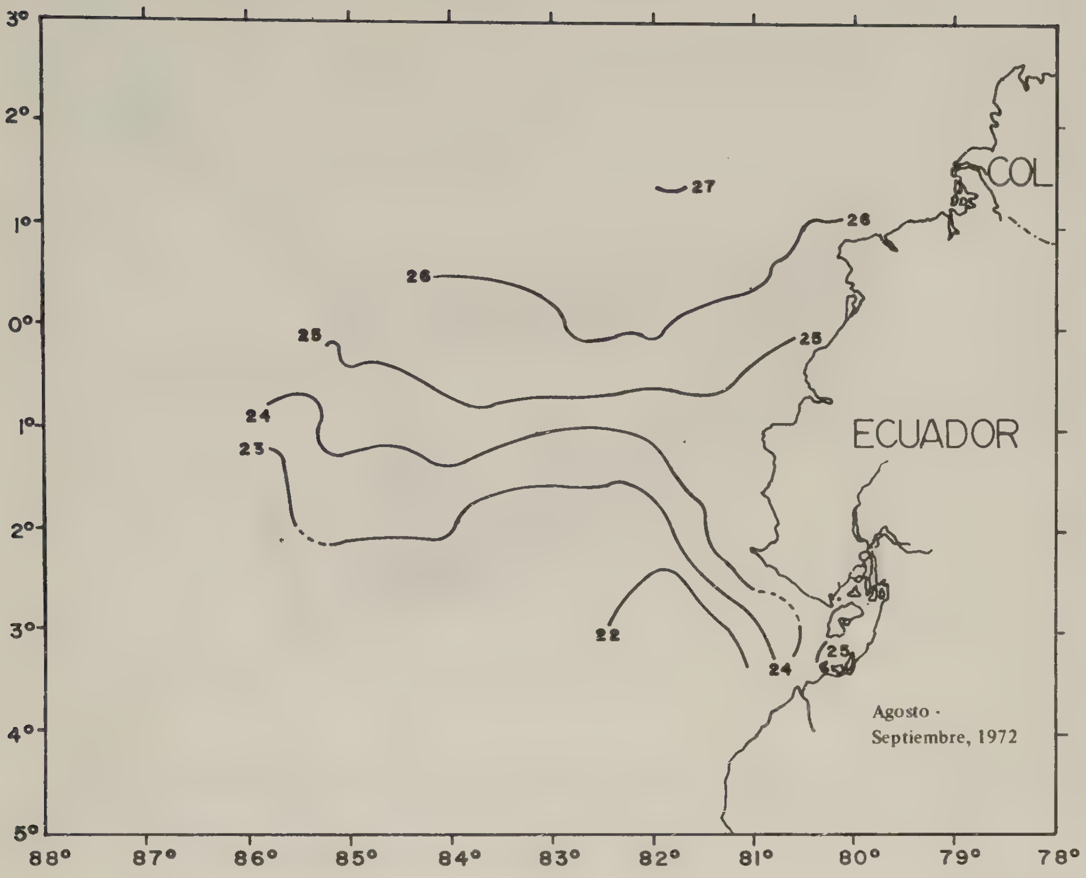

3°
2°
1°
0°
1°
2°
3°
4°
5°
27
26
26
25
25
24
23
22
24
25
COL
ECUADOR
Agosto -
Septiembre, 1972
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 1 Distribución de la temperatura superficial, Crucero BAE "ORION".

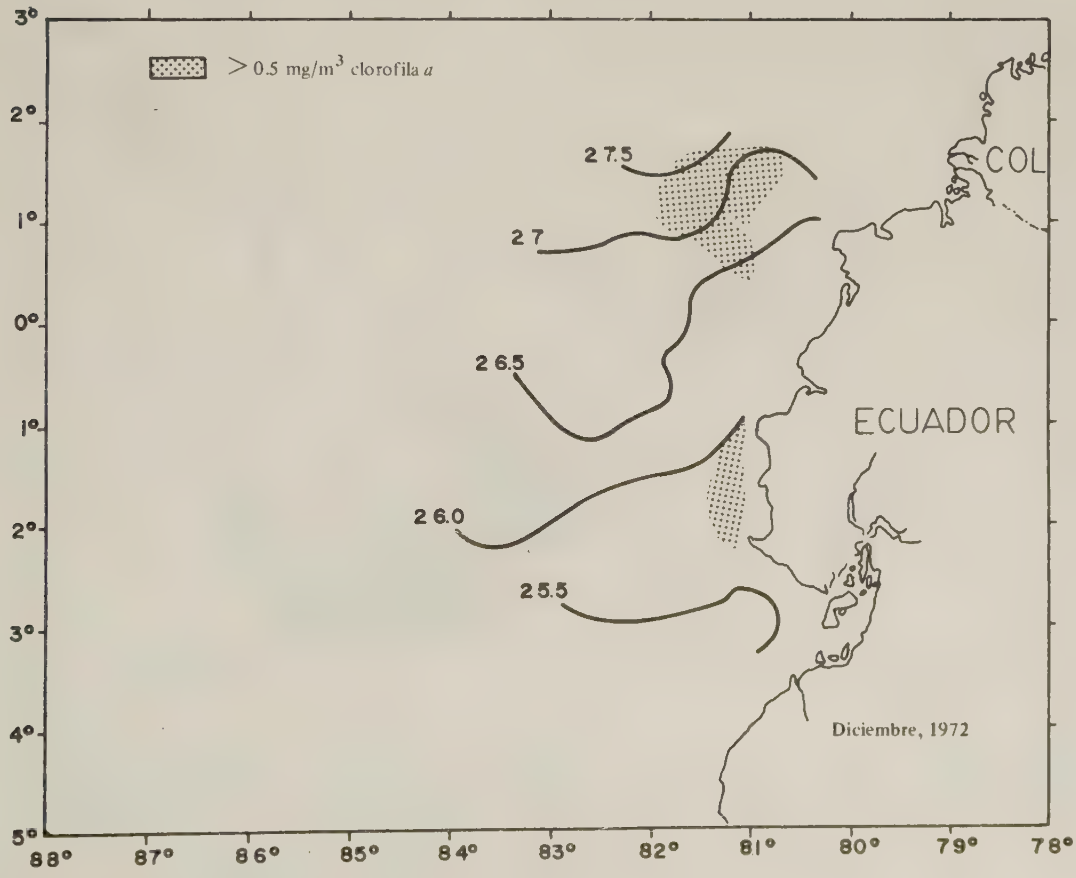

3°
2°
1°
0°
1°
2°
3°
4°
5°
▨ > 0.5 mg/m³ clorofila *a*
27.5
27
26.5
26.0
25.5
COL
ECUADOR
Diciembre, 1972
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 2 Distribución de la temperatura superficial y clorofila *a*. Crucero BAE "ORION".

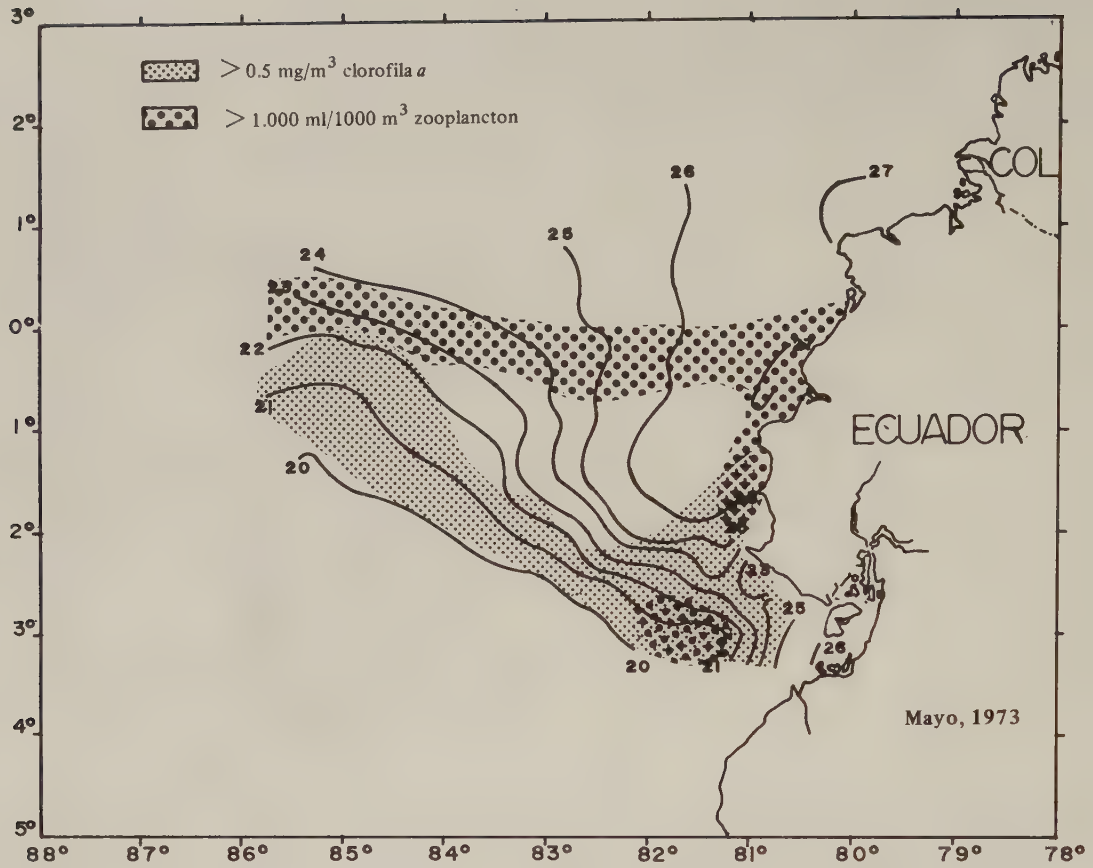

> 0.5 mg/m³ clorofila a
> 1.000 ml/1000 m³ zooplancton
COL
ECUADOR
Mayo, 1973
20
21
22
23
24
25
26
27
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 3 Distribución de la temperatura superficial clorofila *a* y zooplancton. Crucero BAE "ORION".

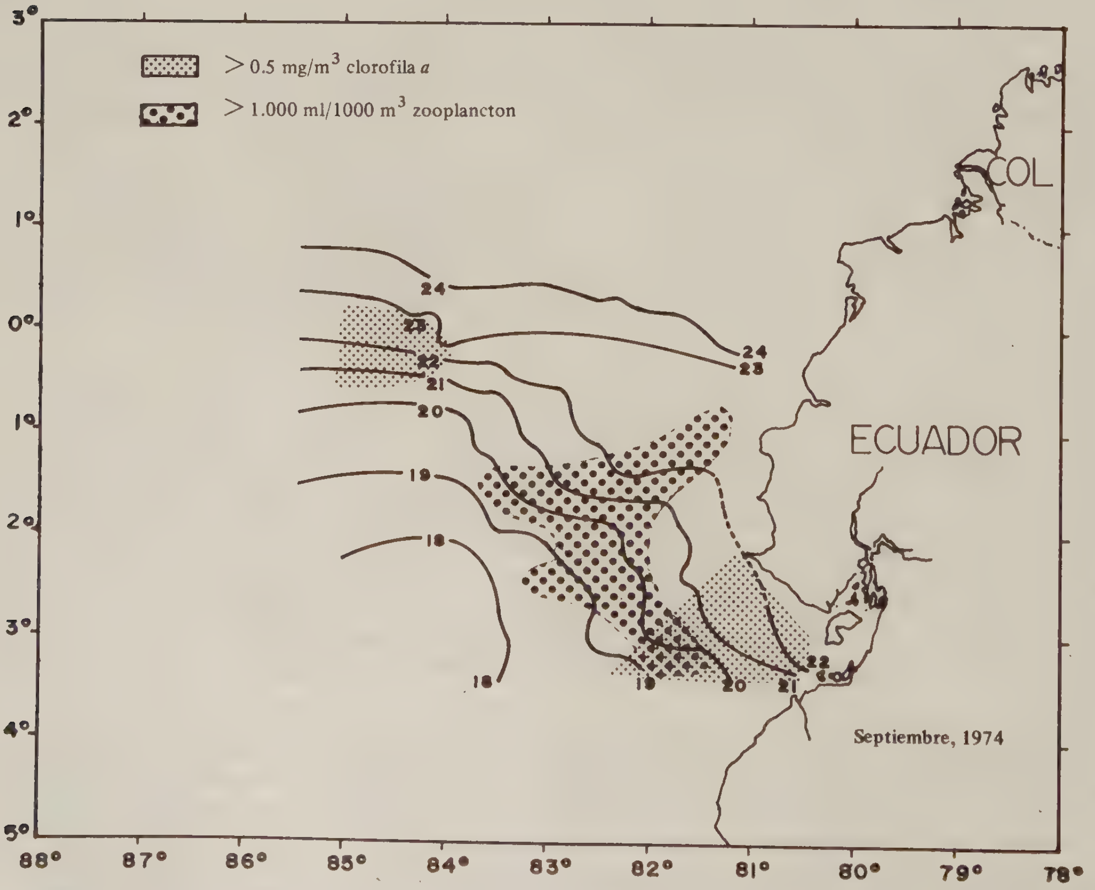
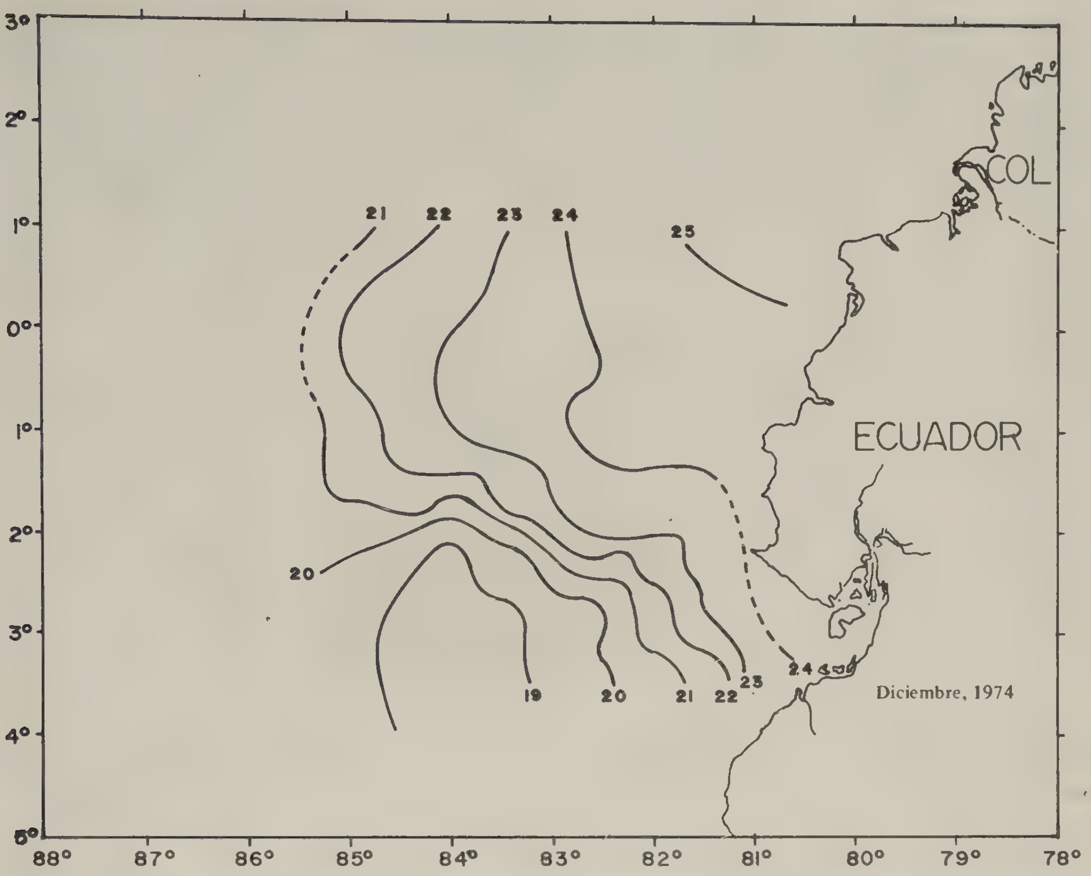

> 0.5 mg/m³ clorofila a
> 1.000 ml/1000 m³ zooplancton
COL
ECUADOR
Septiembre, 1974
18
19
20
21
22
23
24
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 4 Distribución de la temperatura superficial, clorofila *a* y zooplancton. Crucero BAE "ORION".


3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
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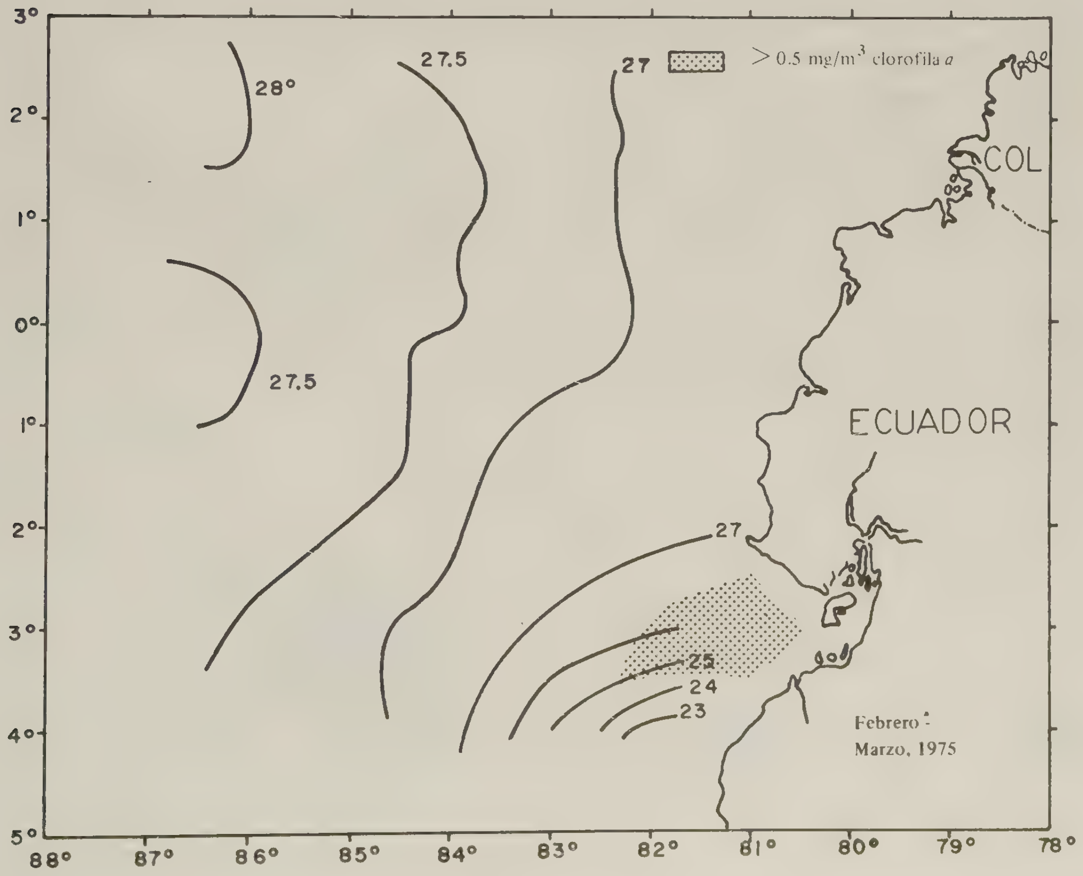
83°
82°
81°
80°
79°
78°
21
22
23
24
25
20
19
20
21
22
23
24
COL
ECUADOR

Diciembre, 1974

Fig. 5 Distribución de la temperatura superficial. Crucero BAE "ORION".


3°
2°
1°
0°
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2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°
28°
27.5
27
27.5
27
25
24
23
▨ > 0.5 mg/m³ clorofila a
COL
ECUADOR

Febrero - Marzo, 1975

Fig. 6 Distribución de la temperatura superficial y clorofila *a*. Crucero R/V "MOANA WAVE".

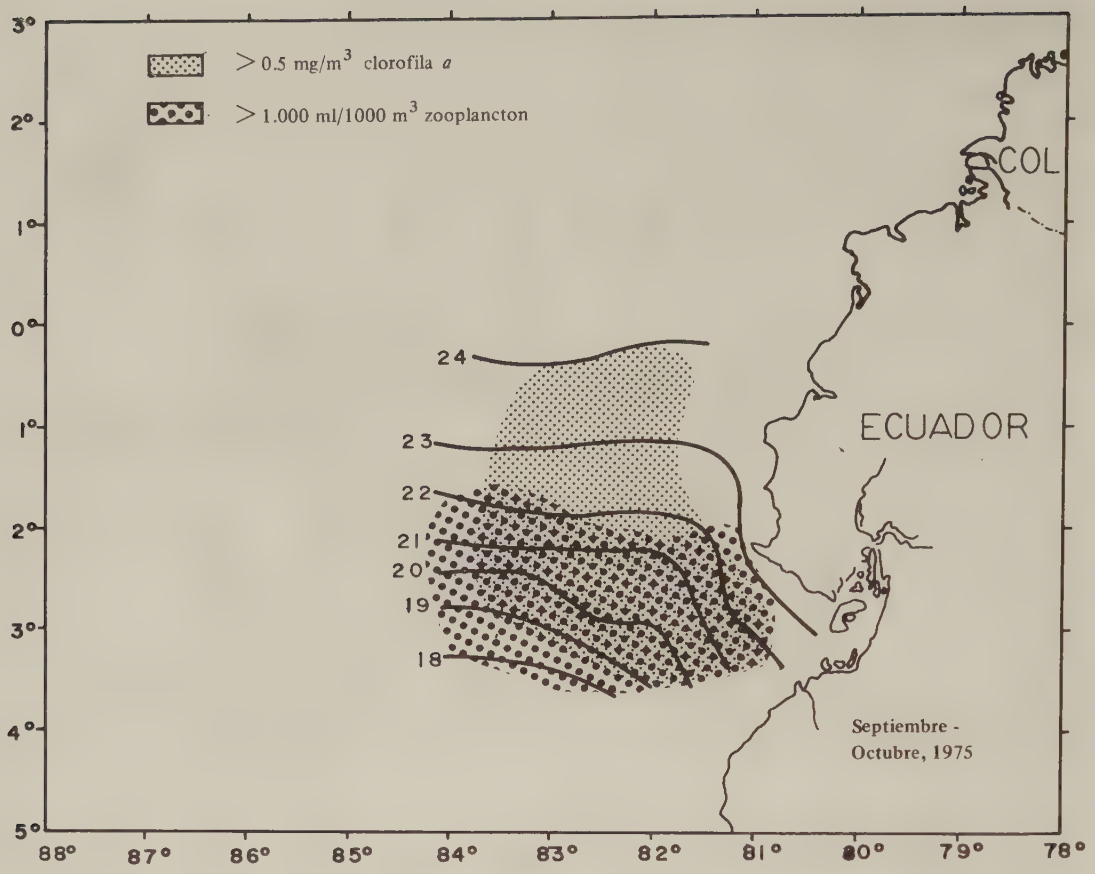

> 0.5 mg/m³ clorofila a
> 1.000 ml/1000 m³ zooplancton
COL
ECUADOR
24
23
22
21
20
19
18
Septiembre -
Octubre, 1975
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 7 Distribución de la temperatura superficial, clorofila *a* y zooplancton. Crucero B/I "HUAYAIPE".

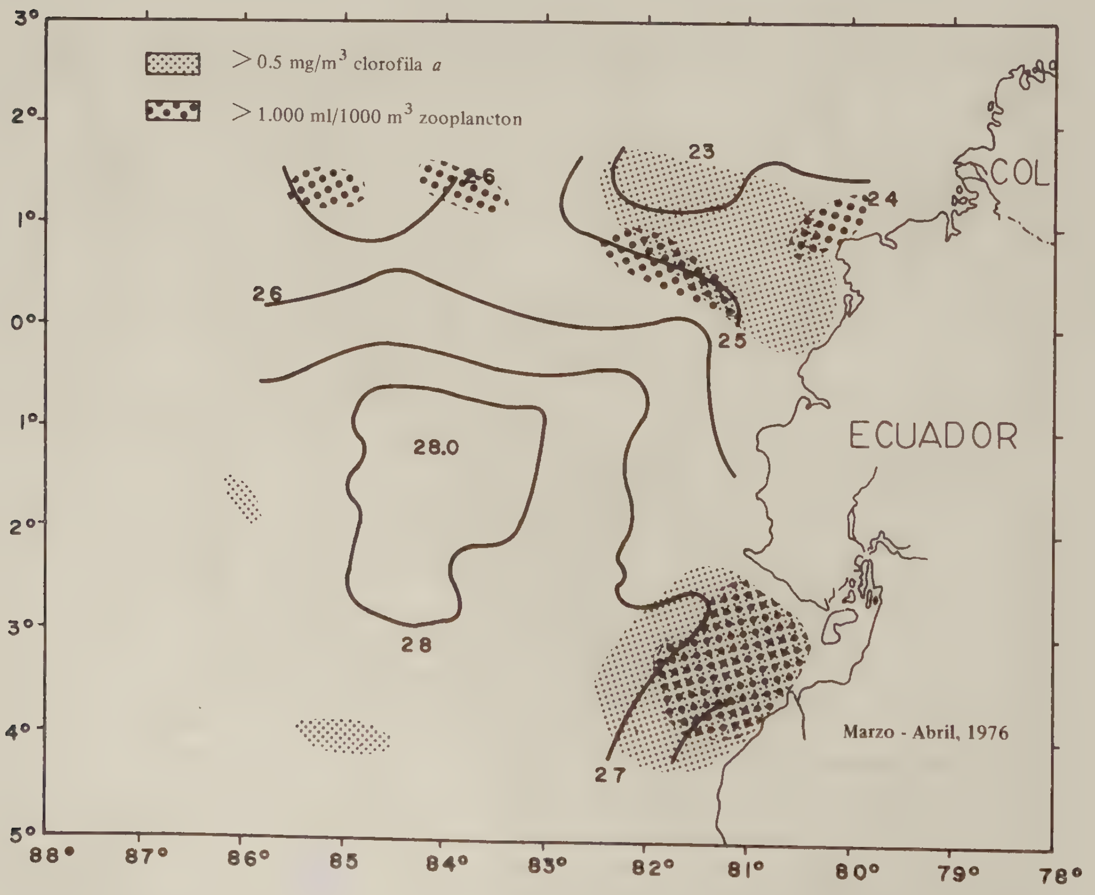

> 0.5 mg/m³ clorofila a
> 1.000 ml/1000 m³ zooplancton
COL
ECUADOR
23
26
24
26
25
28.0
28
27
Marzo - Abril, 1976
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85
84°
83°
82°
81°
80°
79°
78°

Fig. 8 Distribución de la temperatura superficial, clorofila *a* y zooplancton. Crucero BAE "ORION".

En Septiembre, 1974 (Fig. 4) el Frente Ecuatorial estuvo bastante desarrollado, con una posición Noroeste-Sureste y caracterizada por un gradiente de temperatura entre 18ºC a 24ºC y salinidades entre 35.0º/oo a 33.0º/oo. Las más altas concentraciones de fitoplancton estuvieron localizadas al Sur del frente, decreciendo sus concentraciones hacia el noreste. Las diatomeas y cocolitofóridos predominaron al Sur, asociadas al límite de las aguas más frías, mientras que los dinoflagelados predominaron hacia el noreste, donde se localizaron las aguas más cálidas y dispersas del gradiente termohalino, con temperaturas sobre los 23ºC. Las más altas biomasas de zooplancton se localizaron en el límite sur del frente así como también en las aguas intermedias o de transición del frente. Los volúmenes más bajos estuvieron localizados hacia el noreste, o en el límite septentrional del frente. Las concentraciones de copépodos superiores al 50º/o del total del zooplancton, estuvieron localizadas en el gradiente termohalino más fuerte, disminuyendo las concentraciones en dirección a la costa donde el gradiente térmico fue menos marcado. En general, se observó que las máximas concentraciones de copépodos estuvieron asociados a los gradientes más fuertes de temperatura, salinidad y densidad. Los eufaúsidos también mostraron una tendencia hacia las aguas intermedias del frente, encontrándose las concentraciones máximas, conjuntamente con los máximos de fitoplancton, en el norte y sur de la zona frontal. Los valores disminuyeron en forma significativa, al Noreste, en las aguas cálidas y poco salinas, que fueron las más pobres a través del año. Por el contrario, los porcentajes mayores de Quetognatos, se registraron al Noreste, en las estaciones con débil gradiente. En general la distribución y concentración de los diferentes grupos del zooplancton estuvieron relacionados a las condiciones hidrográficas, que caracterizaron el frente.

Aunque los valores disponibles de biomasa zooplanctónica están muy dispersos, es evidente que el grupo de estaciones con una densidad superficial (1 m) elevada, localizada al sur del frente presentó un promedio que fue (2 a 3 veces mayor que el grupo de estaciones con inferior densidad superficial, situadas al norte del frente, (Jiménez y Bonilla, 1980).

En Diciembre de 1974 (Fig. 5) se observó aún la presencia del gradiente térmico del frente, con temperaturas que fluctuaron entre 19ºC y 24ºC, pero la posición de las isotermas, estuvieron orientadas, generalmente en forma paralela a la costa, con un fuerte desplazamiento de las isotermas de 23ºC y 24ºC hacia el sur y muy próximas a la costa como empujando a las aguas más frías hacia la región oceánica donde el gradiente termohalino era más fuerte debido a la influencia de las aguas frías de la Corriente de Humboldt.

En Febrero y Marzo de 1975 (Fig. 6) las condiciones oceanográficas que tipifican el fenómeno de El Niño estuvieron presentes frente al Ecuador (Wyrtki, Stroup, Patzert, Williams y Quinn, 1976) con la advencción de aguas cálidas procedentes del norte, con temperaturas de aproximadamente 27ºC y salinidad baja de 33,5º/oo. Solamente al sur, en el Golfo de Guayaquil, se registró un pequeño frente térmico, donde se observaron concentraciones relativamente altas de clorofila *a*. Aunque El Niño de 1975 fue considerado de débil intensidad, la producción primaria se redujo a una quinta parte de los valores normalmente encontrados entre las Islas Galápagos y el continente, a causa de los afloramientos ecuatoriales (Cowles, Barber y Guillen, 1977) y del Frente Ecuatorial. También el zooplancton no alcanzó en esta época su máxima biomasa, registrándose la concentración más elevada de 700 ml/100 $m^3$ en un pequeño parche, a la altura del Golfo de Guayaquil.

Como El Niño fue de corta duración ya en los meses de Abril y Mayo, se restablecieron las condiciones normales en el área del Frente Ecuatorial. En Septiembre - Octubre de 1975 (Fig. 7), el Frente Ecuatorial se manifestó en forma bastante desarrollado, en dirección perpendicular a la costa con un fuerte gradiente termohalino, especialmente en el límite sur, ligado a las aguas más frías de 18ºC y 19ºC, donde se observó una marcada divergencia. Con el desarrollo de este frente se originó una alta concentración de fitoplancton en la que predominaron las diatomeas, hasta el límite norte del frente próximo a las aguas más cálidas con temperaturas de 24ºC. En forma similar, se observó una expansión del máximo de zooplancton ($>$1000 ml/1000 $m^3$) en dirección del máximo gradiente del frente, que correspondió al límite de las aguas más frías de la zona frontal. Al parecer la mezcla de las dos masas de agua, con características complementarias se manifestaron en un fuerte gradiente horizontal y vertical, que posiblemente incrementó la producción planctónica en una extensa zona del océano relacionada con el Frente Ecuatorial.

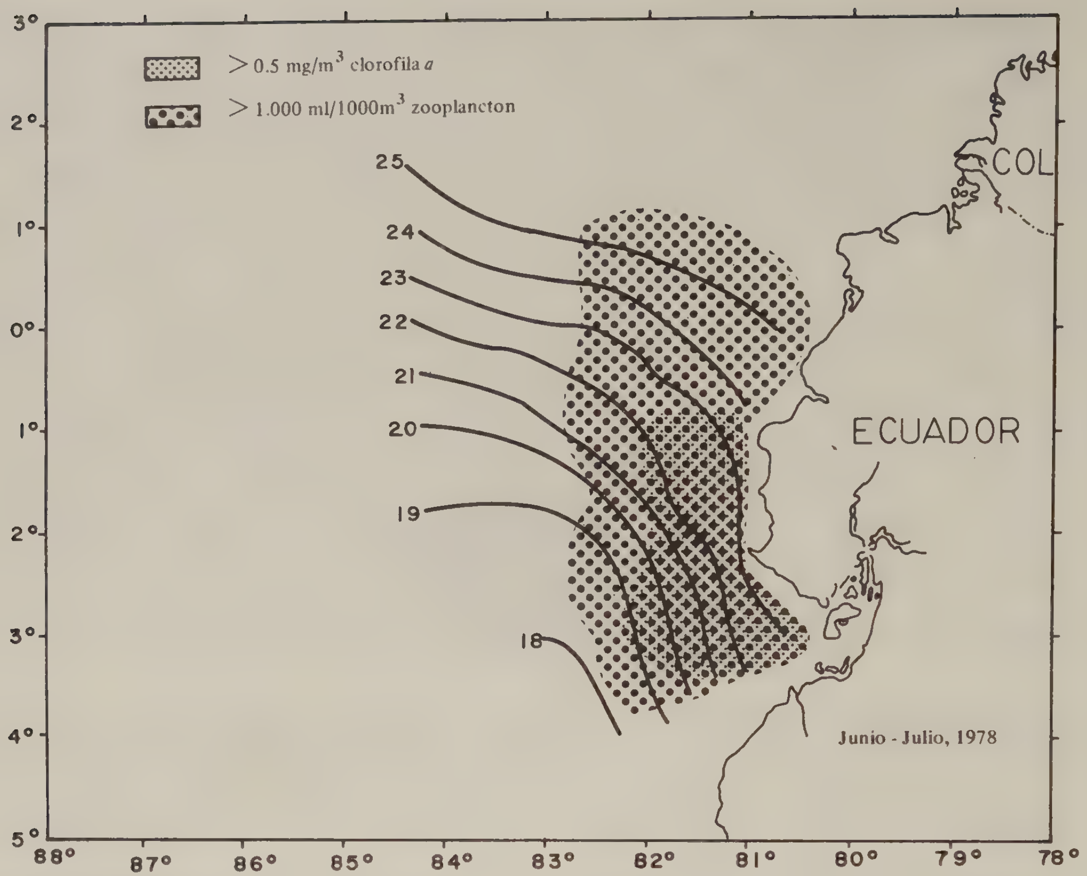

> 0.5 mg/m3 clorofila a
> 1.000 ml/1000m3 zooplancton
25
24
23
22
21
20
19
18
COL
ECUADOR
Junio - Julio, 1978
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 9 Distribución de la temperatura superficial, clorofila *a* y zooplancton. Crucero BAE "ORION".

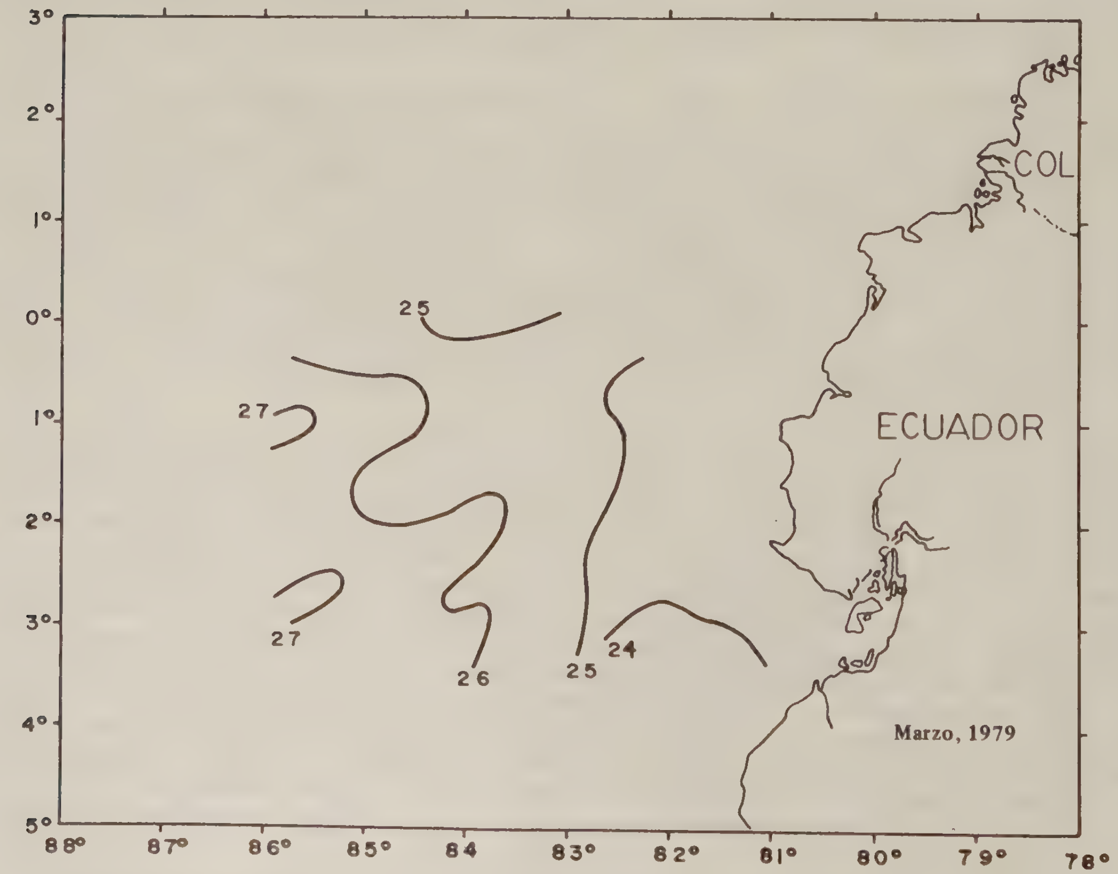

25
27
27
26
25
24
COL
ECUADOR
Marzo, 1979
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84
83°
82°
81°
80°
79°
78°

Fig. 10 Distribución de la temperatura superficial. Crucero BAE "ORION".

En Marzo y Abril de 1976 (Fig. 8) se produjo frente a las costas de Ecuador, una invasión de aguas superficiales cálida y de baja salinidad, de alrededor de 28°C y 33,6 - 33,8°/oo, respectivamente. Estas procedían del suroeste y avanzaron hasta cerca de 0°. Simultáneamente se evidenció también, un estrecho flujo costero hacia el sur, de aguas anormalmente cálidas de 26°C a 27°C pero con salinidad relativamente mayor de 34.0 - 43.2°/oo provenientes de la Bahía de Panamá. Al analizar las características de la columna de agua desde 1°30' hasta 3°S de la posición 82°30'W, demostró que la advección de aguas cálidas de baja salinidad procedentes del Suroeste en los meses de Marzo y Abril presentaban características propias del agua Tropical Superficial (Cucalón, 1982).

Conjuntamente con las aguas más cálidas se presentaron concentraciones bajas de diatomeas clorofila *a* y producción primaria. Por el contrario, predominaron los dinoflagelados, en densidades de hasta 130,000 cel m$^3$, especialmente de *Gymnodinium* ssp. aumentando desde la costa hacia el océano abierto. También se encontraron abundantemente los dinoflagelados típicos de aguas cálidas como *Pyrophacus horologicum, Blepharocystis splendormaris* y *Gonodioma poliedricum,* así como también las distintas especies del genero *Ceratium.* Es importante mencionar, que el máximo de fitoplancton se encontró más restingido en el área del Golfo de Guayaquil con pequeños parches en el océano abierto asociados a las altas concentraciones de *Gymnodinium.* Esto contrastó con lo sucedido en el Niño de 1975.

En cambio hacia el norte, en el área donde se encontró las más bajas temperaturas de 23°C y 25°C, se localizó otro máximo de fitoplancton con predominio de diatomeas, en concentraciones de 1'500,000 cel m$^3$. Las especies de diatomeas *Rhizosolenia styliformis, Rhizosolenia alata* y *Thalassiotrix gibberulla* fueron identificadas en las áreas más oceánicas, mientras que en las inmediaciones de la costa, predominaron las especies de *Chaetoceros,* como *Ch. lacimiosus* y *Ch. coartatus.* En general se puede decir que las variaciones de las poblaciones diatomeas - dinoflagelados al norte y sur del ecuador reflejaron las diferentes condiciones hidrográficas de las dos áreas.

Por otra parte con respecto al zooplancton los máximos estuvieron restringidos al área del Golfo de Guayaquil y a pequeños parches al norte del ecuador, en aguas oceánicas y costeras posiblemente asociados al máximo de fitoplancton registrado en esta área (Jiménez, 1982).

En Septiembre, 1982 las condiciones oceanográficas de las aguas costeras del Ecuador habían retornado a lo normal con la formación de un intenso Frente Ecuatorial entre 1°N (26°C y 33.0°/oo) y 2°S(20°C y 35.0°/oo).

En Junio - Julio de 1978 (Fig. 9) el frente presentó uno de los gradientes más fuertes registrados en todo el año, con una definida posición Noroeste-Sureste, observándose que los gradientes más fuertes localizados al sur, en la zona externa del Golfo de Guayaquil, mostraban una diferencia de 4°C cada 60 millas.

El gradiente térmico horizontal estaba caracterizado con temperaturas de 18°C al sur y 25°C al norte.

La importancia primordial de la formación y posición del frente reside en el hecho de que aguas ricas en nutrientes son transportadas a la zona eufótica costera, dentro de la zona frontal enriqueciendo con este mecanismo, las aguas costeras adyacentes al Ecuador. Cabe mencionar, que la estabilidad vertical en el área frontal es mucho más débil en las proximidades de la costa que mar afuera. Además los niveles de luz son inferiores en las vecindades de la costa que fuera de ella, debido a la mezcla vertical. Aparentemente, la presencia de cantidades sustanciales de nutrientes, son difundidos en todo el frente, a causa de una capa de mezcla bastante superficial que produce una alta concentración de fitoplancton y alta producción primaria. La picnoclina relativamente superficial, concentra a las células del fitoplancton en la zona de luminosidad, al mismo tiempo, que favorece la multiplicación celular.

Asociado a esta alta densidad del fitoplancton, se presentan concentraciones de zooplancton a lo largo de, todo el frente tendiendo a ser mayor en dirección a la costa. Posiblemente estos hechos están favorecidos por la posición de los gradientes termohalinos y la advenccíón superficial, los cuales determinan la localización y magnitud de los varios componentes biológicos del ecosistema frontal.

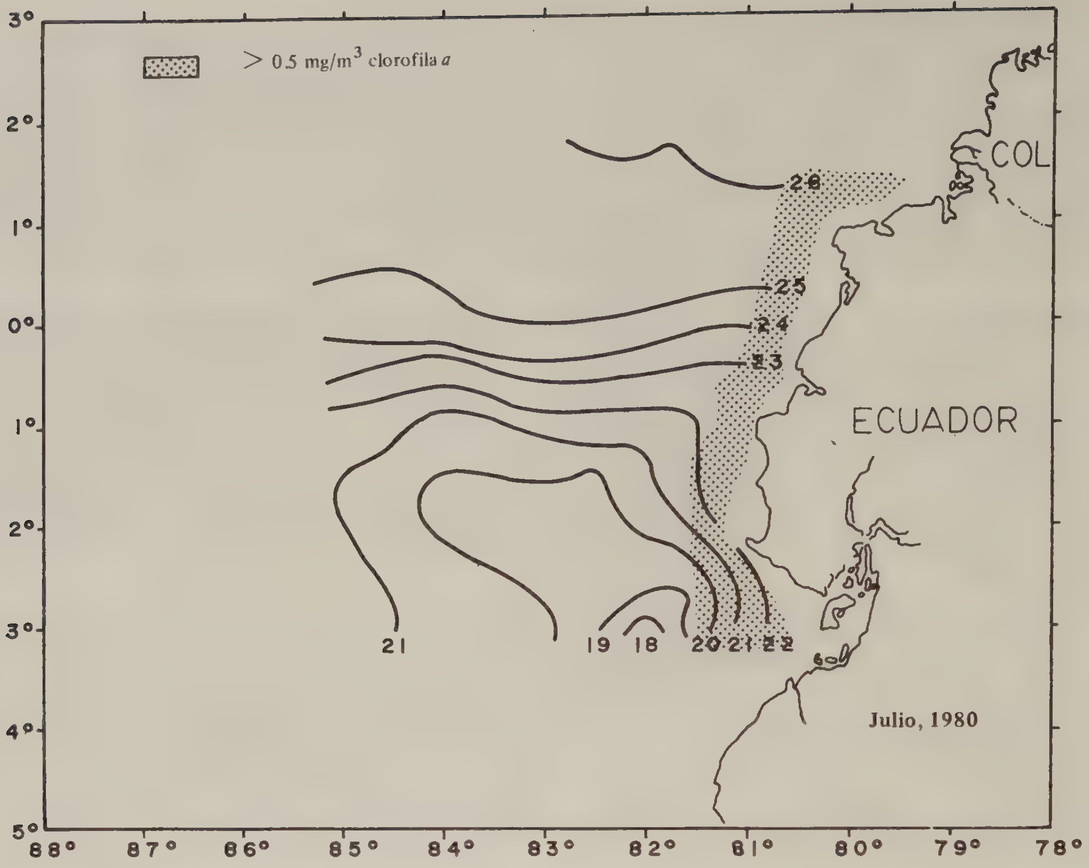

▨ > 0.5 mg/m³ clorofila *a*
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°
COL
ECUADOR
26
25
24
23
21
19
18
20
21
22
Julio, 1980

Fig. 11 Distribución de la temperatura superficial y clorofila *a*. Crucero B/I "TOHALLI".

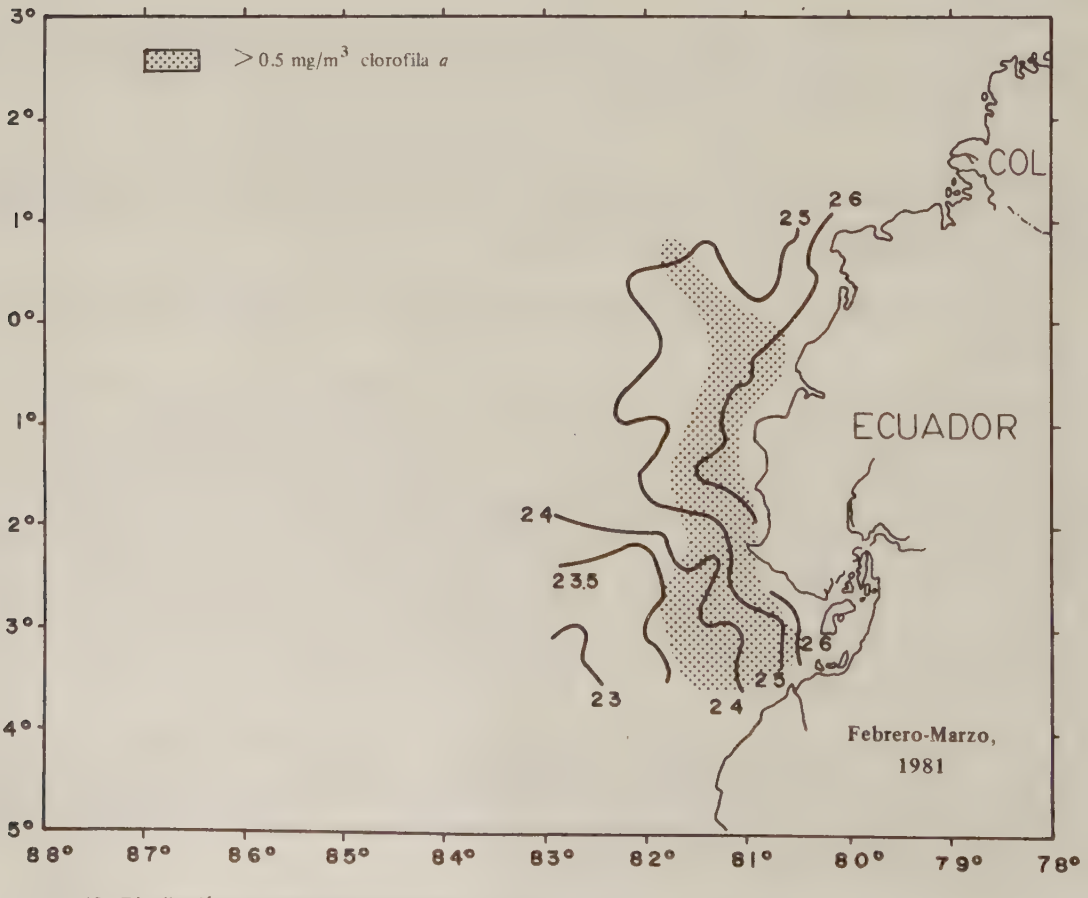

▨ > 0.5 mg/m³ clorofila *a*
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°
COL
ECUADOR
26
25
24
23.5
23
24
25
26
Febrero-Marzo, 1981

Fig. 12 Distribución de la temperatura superficial y clorofila *a*. Crucero B/I "TOHALLI".

En Marzo de 1979 (Fig. 10) no se registró la presencia del frente, observándose el avance de aguas cálidas desde el oeste con temperaturas de 26°C y 27°C. En las inmediaciones de la costa, las temperaturas fluctuaron entre 24°C y 25°C, sin mostrar ningún patrón característico de distribución. A pesar de no disponer de la información correspondiente al fitoplancton o zooplancton de esta época, se cree que una productividad planctónica relativa debe de haberse registrado a lo largo de la costa, al considerar que las temperaturas no fueron superiores a los 25°C. De acuerdo a lo mencionado anteriormente, cuando durante estos meses (Febrero - Marzo - Abril) se registran temperaturas sobre lo normal, aunque la distribución del máximo de fitoplancton sea limitada y muy cercana de la costa como en Febrero, Marzo de 1975, se puede especular que esta productividad planctónica relativa fue suficiente para proveer de alimento y asegurar la supervivencia de las larvas y peces pelágicos sin afectar estas pesquerías, las cuales según las informaciones hasta 1981 han continuado experimentando un incremento en sus capturas.

En Julio de 1980 (Fig. 11) el frente presentó características un tanto distintas que aquel de Junio y Julio de 1978, en lo referente a la distribución del gradiente térmico, el mismo que presentó la modalidad de un meandro, por la fuerte influencia del agua fría procedente del sur, que originó un marcado gradiente en el área externa del Golfo de Guayaquil en dirección Noroeste - Sureste, desde 1°S hasta los 3°S. Hacia el norte, el gradiente térmico mostró una tendencia a proyectarse más perpendicularmente a la costa, con un mayor espaciamiento de la isoterma de 26°C hacia el norte de la latitud ecuatorial.

Con respecto a los máximos de fitoplancton éstos se presentaron muy cerca de la costa decreciendo sus concentraciones hacia el océano abierto, la misma tuvo una amplia distribución norte-sur a lo largo de toda la costa ecuatoriana, con un patrón similar al registrado en esta misma época, para otros años.

En Febrero y Marzo de 1981 (Fig. 12), la orientación paralela de las isotermas, con respecto a la costa reveló fundamentalmente la ausencia del Frente Ecuatorial. A los 2°S, la orientación de las isotermas podría sugerir el desplazamiento del frente hacia el sur. Aparentemente hubo una estrecha transgresión de aguas costeras de alta temperatura (26°C - 27°C) provenientes del norte, las cuales avanzaron hasta cerca de 2°S. Las temperaturas más altas se las encontró en aguas muy cercanas a la costa (27°C), disminuyendo hacia el Oeste y Suroeste. Este esquema de distribución de las temperaturas superficiales, en realidad se lo puede considerar "normal", ya que, con ligeras variaciones produce regularmente durante esta época del año. (Cucalón, 1981).

Por otra parte, es importante señalar, que en la distribución vertical de la temperatura y salinidad, esta área mostró gradientes muy marcados de hasta 8°C, entre la superficie (1 m) y los 40 m de profundidad, indicando una fuerte estabilidad de los estratos superficiales de la columna de agua. Esto posiblemente favoreció la amplia distribución del máximo de fitoplancton a lo largo de la costa del Ecuador, y la consecuente disponibilidad de alimento para los primeros estadios de las larvas de especies pelágicas, durante esta época en que son más importantes los desoves (García, 1983).

En agosto de 1981 (Fig. 13) el Frente Ecuatorial se encontraba bastante desarrollado, con una orientación típica, en sentido Noroeste - Sureste y próximo a las costas; mientras que hacia el sur, en el Golfo de Guayaquil, los gradientes adoptaron una dirección Norte - Sur. Las temperaturas en el frente variaron desde 19°C al sur hasta 25°C al norte, en una distancia aproximada de cien millas, (Cucalón, 1981 a). Con respecto a la distribución vertical de las isotermas, isohalinas e isopicnas, en el frente, se observó una marcada divergencia, especialmente entre 1°S y 2°S, donde se registró también gradientes horizontales más intensos. Hacia el sur de esta área, se observó una marcada divergencia, especialmente entre 1°S y 2°S, donde de registró también gradientes horizontales más intensos. Hacia el sur de esta área, se observó una convergencia que se caracterizó por el hundimiento de los valores de oxígeno hasta cerca de los 40 m de profundidad. Los máximos de fitoplancton estuvieron relacionados a los gradientes termohalinos, donde se observó la divergencia, extendiéndose este máximo desde el océano abierto hacia la costa sur.
Esto nos indica que la formación del frente constituye un mecanismo físico de particular importancia en la distribución y mantenimiento de la fertilidad del fitoplancton en aguas costeras oceánicas del Ecuador, lo que repercute en la fertilidad biológica de otros niveles tróficos de la cadena alimentaria.

En Noviembre - Diciembre de 1982 (Fig. 14) se presentaron las condiciones oceanográficas que tipifican las manifestaciones del fenómeno El Niño, con un incremento significativo de la temperatura del agua a lo largo de toda la costa con temperaturas entre 25°C a 26°C y 27°C a 28°C al norte, con un patrón de distribución similar al observado en Diciembre de 1972. Se registró una drástica disminución del máximo de fitoplancton, a lo largo de la costa restringiéndose el mismo al sur de la costa de Ecuador, en el área externa del Golfo de Guayaquil.

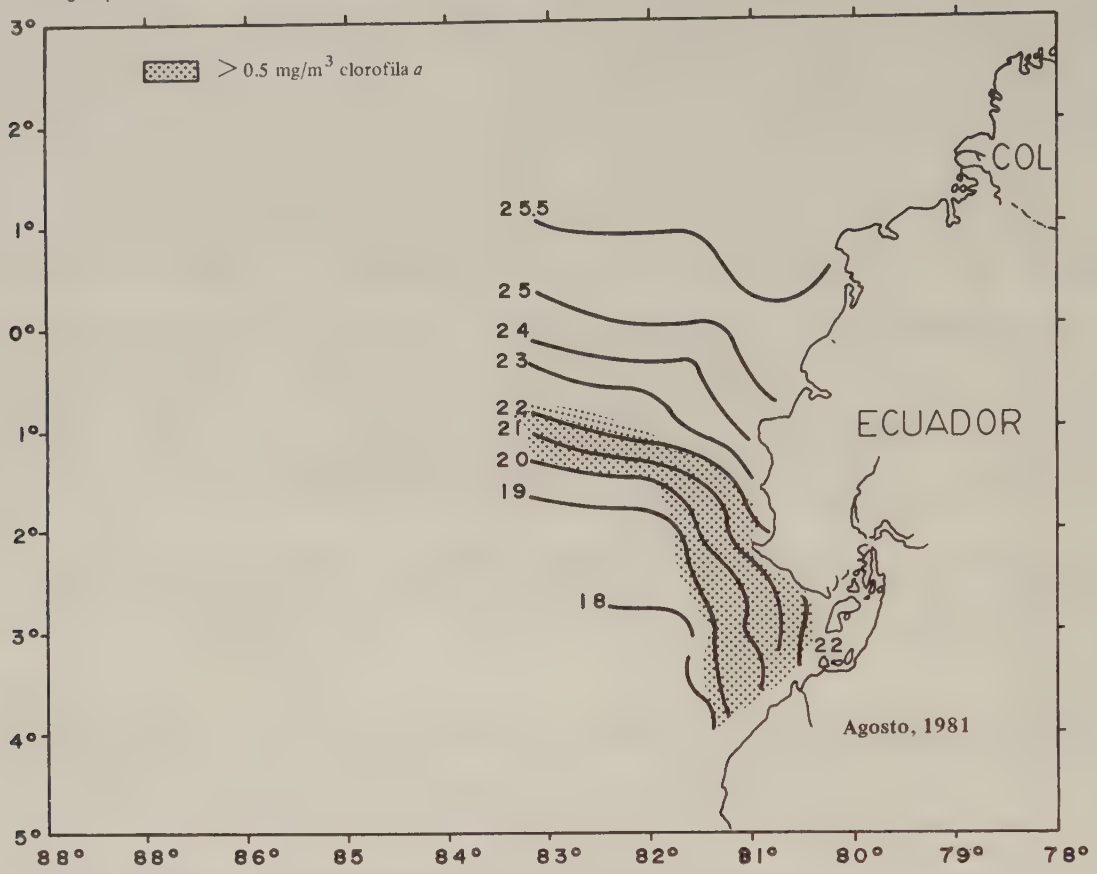

> 0.5 mg/m³ clorofila *a*
COL
ECUADOR
25.5
25
24
23
22
21
20
19
18
22
Agosto, 1981
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
88°
86°
85
84°
83°
82°
81°
80°
79°
78°

Fig. 13 Distribución de la temperatura superficial y clorofila *a*. Crucero B/I "TOHALLI"

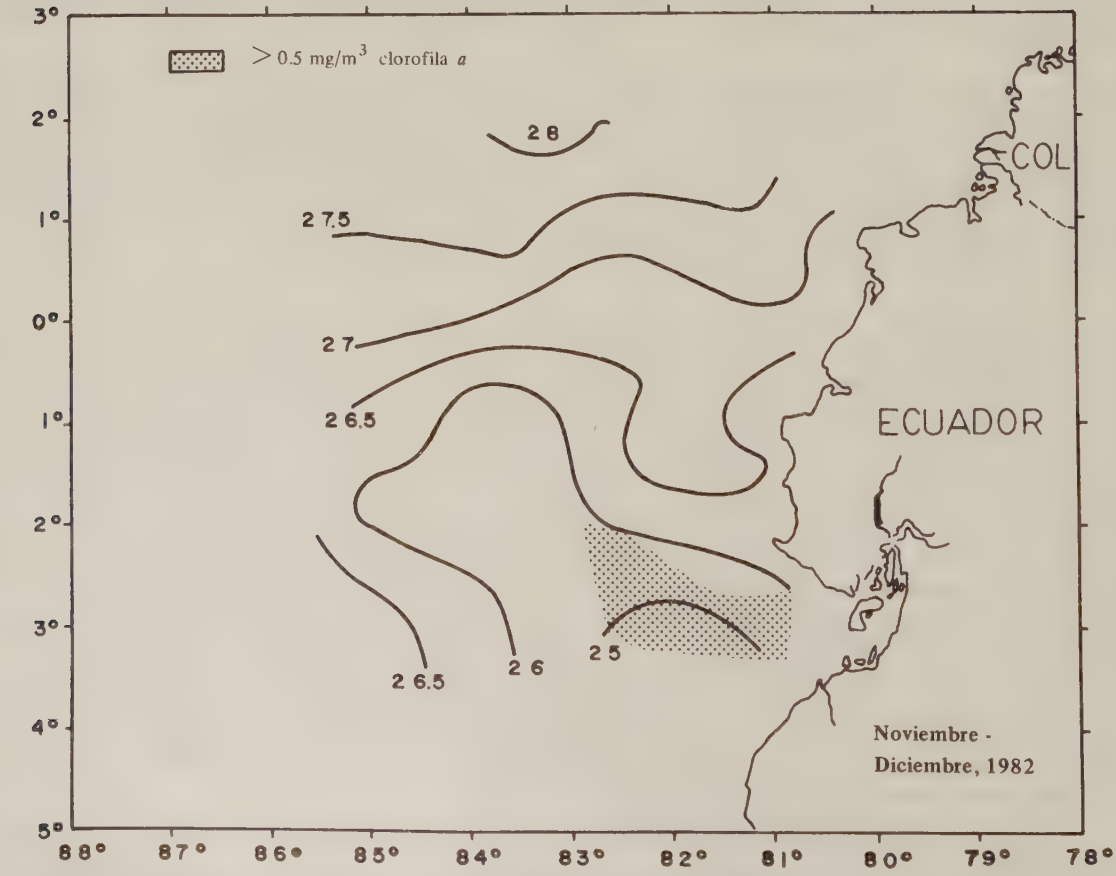
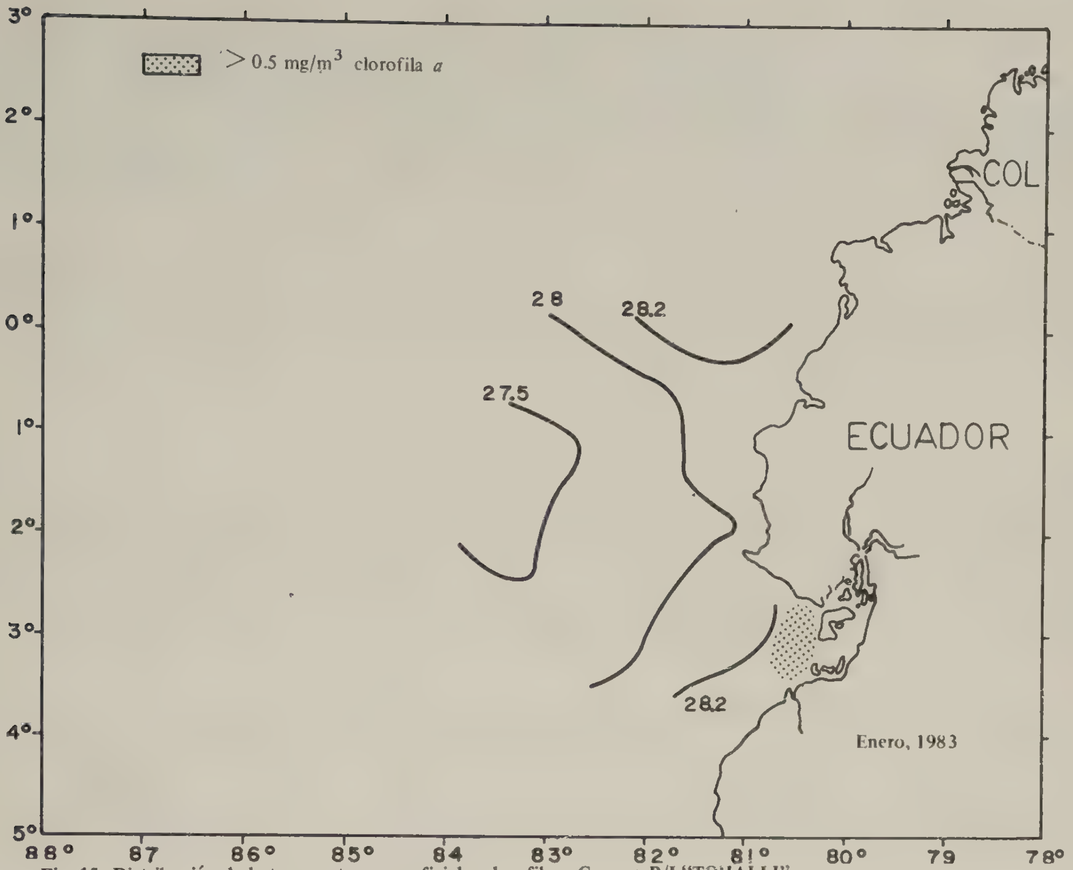
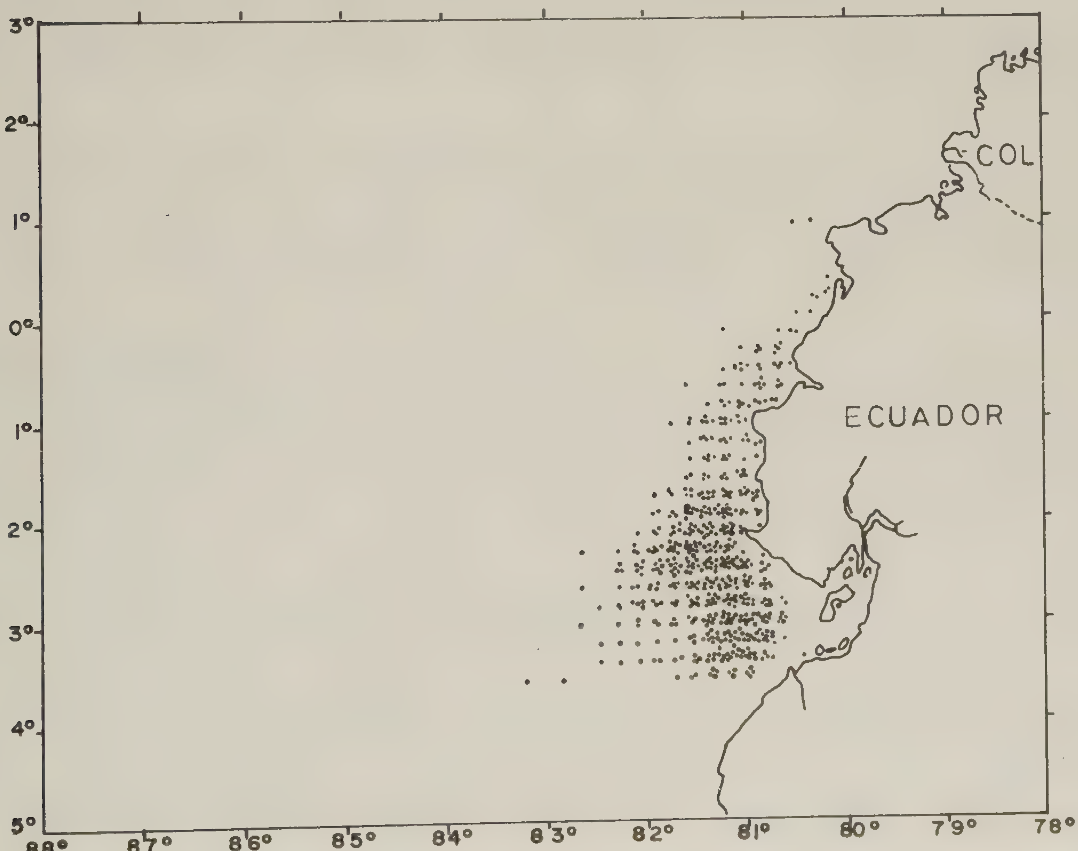

> 0.5 mg/m³ clorofila *a*
28
COL
27.5
27
26.5
ECUADOR
26.5
26
25
Noviembre - Diciembre, 1982
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 14 Distribución de la temperatura superficial y clorofila *a*. Crucero B/I "Tohallí".



> 0.5 mg/m³ clorofila a
COL
ECUADOR
28
28.2
27.5
28.2
Enero, 1983
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87
86°
85°
84
83°
82°
81°
80°
79
78°

Fig. 15 Distribución de la temperatura superficial y clorofila *a*. Crucero B/I "TOHALLI".



COL
ECUADOR
3°
2°
1°
0°
1°
2°
3°
4°
5°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°

Fig. 16 Distribución de las capturas de macarela Scomber japonicus por la flota pesquera ecuatoriana durante 1981.

En Enero de 1983 (Fig. 15) se observó en toda el área del Golfo de Guayaquil y hacia el océano abierto, hacia el oeste de los 82ºW, incrementos en la temperatura superficial del mar, asociadas a salinidades bajas. En este mes se registró una marcada disminución del máximo de fitoplancton restringiéndose a una estrecha banda en el Golfo de Guayaquil. Concentraciones bajas de fitoplancton se mantienen en toda la columna de agua de área, investigada hasta los 50 m de profundidad. Para esta época se observó cambios importantes en la composición del fitoplancton, con la predominancia de los dinoflagelados en relación a las poblaciones de diatomeas que normalmente son predominantes hacia el Sur de la costa del Ecuador. Se registró la predominancia del dinoflagelado *Pyrophacus horologicum* y *Blepharocystis splendormaris*, así como varias especies de *Ceratium*, estas especies también se las encontró predominantes durante El Niño de 1972 y 1976. Uno de los aspectos más relevantes observados durante El Niño de 1982 - 1983 fue la ausencia de desoves de las especies de peces pelágicos, en una época que como 1981 fueron abundantes, (García, 1983).

## DISCUSION

En el Frente Ecuatorial, determinadas características estacionales se mantienen de año a año; sin embargo, se observan algunas diferencias, no sólo en lo que se refiere a la intensidad y duración del evento, sino también a fluctuaciones en pequeña escala, de ciertas propiedades inherentes al ecosistema marino que constituye el Frente. Su posición y orientación en el mar costero ecuatoriano y la intensidad de las termohalinas a través de los años y en las diferentes épocas de un mismo año, son las características más notables, que identifican la magnitud de su desarrollo y su repercusión en la vida acuática.

Las condiciones hidrográficas del frente, determinan la formación de zonas de convergencia y divergencia, en los niveles superficiales, las cuales favorecerían el incremento local de las biomasas planctónicas y la vida acuática de peces pelágicos, tales como *Scomber japonicus*, (Fig. 16), *Sardinops sagax*, y *Etrumeus teres* principalmente. La pesca de estas especies se circunscribe al límite sur de la zona frontal, coincidente con los gradientes termohalinos más fuertes, y con los máximos del fitoplancton y zooplancton. Las capturas disminuyen al norte y suroeste, donde los gradientes térmico-salinos se encuentran más espaciados. La convergencia de masas de agua, tenderían a concentrar o enlazar, cerca de la superficie, a parches de material planctónico que estuviesen diseminados. En cambio, las áreas de divergencia superficial favorecerían la dispersión de los organismos planctónicos y por ende la difusión de los parches del plancton (Parrish, Nelson, y Bakun, 1981) en las áreas de surgencia de gran productividad y concentracion de nutrientes.

Es importante señalar, que en la época de mayor desarrollo de los gradientes termohalinos del frente (Mayo - Septiembre) los máximos de fitoplancton y zooplancton se distribuyen más ampliamente enriqueciendo notablemente las aguas costeras y oceánicas del Ecuador, con el predominio de diatomeas y de altas concentraciones de copépodos y eufaúsidos.

En las épocas cálidas, como Febrero y Marzo de 1981 (Fig. 12) y en condiciones oceanográficas consideradas normales, la mayor productividad del fitoplancton, incluyendo *Mesodinium rubrum*, se presentó a lo largo de la costa del Ecuador; mientras que, durante las condiciones anómalas, tales como las que ocurrieron en El Niño de Diciembre de 1972 y el de Febrero y Marzo de 1975, las áreas de fitoplancton fueron más pequeñas y limitadas al océano abierto. Sin embargo, una relativa productividad primaria, pudo sostener el desarrollo de los primeros estadios larvarios. Al parecer sucedió lo mismo durante el fenómeno de El Niño de 1976 (Fig. 8) donde concentraciones relativamente altas de diatomeas fueron observadas al norte y sur de la costa de Ecuador. En las concentraciones de fitoplancton en el océano abierto disminuyeron en forma significativa predominando los dinoflagelados, típicos de aguas cálidas. Durante el fenómeno El Niño de 1982 - 1983, (Enero de 1983) los avances de aguas cálidas en dirección a la costa con temperaturas de más de 28ºC fueron más críticas. (Fig. 15). Los máximos de fitoplancton se encontraron en una área pequeña y restringida al Golfo de Guayaquil, lo que posiblemente afectó negativamente la supervivencia de las larvas, las cuales no fueron detectadas muy abundantes (García, 1983). Esto determinaría en el futuro, el fracaso de toda una clase anual, desconociéndose además, las consecuencias nefastas que pudieran producirse en las pesquerías de los años siguientes.

Dada la importancia de la formación y evolución del frente en las aguas ecuatorianas, se pretende estudiar próximamente en forma más detallada, su persistencia y disipación, incorporando mayor esfuerzo investigativo en los procesos que originan la fertilidad biológica, que redunda en el desarrollo de las pesquerías pelágicas del Ecuador.

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*SOUTH EAST PACIFIC - PACIFICO SUDORIENTAL*

# VARIABILIDAD EN LA DISTRIBUCION Y ABUNDANCIA DE HUEVOS Y LARVAS DE MACARELA (*Scomber japonicus peruanus*) Y DE ALGUNOS CLUPEIDOS EN AGUAS ECUATORIANAS

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## Summary

The distribution and abundance of eggs and larvae of *Scomber japonicus peruanus* (mackerel) and of some cleupeids were determined on various cruises during some years in the Gulf of Guayaquil and the Coast of Ecuador.

Marked differences were detected in the spawning of these species, which coincided with variations detected in oceanographic conditions and both primary and secondary productivity.

Major abundances were detected during the summer (January to April) with values of 10,000 mackerel eggs 110 $m^2$. Lower values were recorded in winter months (May to December). Major concentrations were encountered principally in the north and south of Ecuador during February and March and limited to the south in August, distinguishing primarily the zone adjacent to the tip of Santa Elena as a zone of intense spawning.

In this study special attention is given to the analysis of information obtained in recent years, and to the variations observed in species distribution.

# INTRODUCCION

En el transcurso de los últimos veinte años, las especies de peces pelágicos que han constituído las pesquerías neríticas más importantes del Ecuador han sido: la pinchagua *(Opisthonema* spp.*)*;el chuhueco *(Cetengraulis mistycetus)*; la macarela *(Scomber japonicus peruanus)*; la sardina del sur *(Sardinops sagax sagax)* y la sardina redonda *(Etrumeus teres)*.

La distribución de las capturas se extiende generalmente de la costa hasta las 20 millas para *Opisthonema* y hasta las 40 millas fuera de la costa para las otras especies (French y Menz, 1982).

Hasta 1970, la especie tropical *Opisthonema spp.* integra casi exclusivamente el total de las capturas por la flota nacional. A mediados de la década del 70 comienza a desarrollarse una pesquería mixta compuesta por especies de distribución circuntropical y subtropical como: *S. japonicus; E. teres* y *S. sagax* que constituyen los recursos más importantes en volúmenes de captura por la flota ecuatoriana en la década actual.

Estos cambios manifestados por las capturas podrían ser atribuidos a factores inherentes con el desarrollo y expansión de las pesquerías, más que a una respuesta biológica de las poblaciones de peces a condiciones ambientales.

Según Smith (1980), el monitoraje de la captura por unidad de esfuerzo, cuando se trata de stocks pequeños, no es un método muy confiable para la determinación de las características de la población en sí. En nuestro caso el monitoraje de huevos y larvas de peces ha sido útil en la interpretación de los eventos que en pequeña o gran escala han determinado los cambios en la distribución y abundancia de la población desovante de macarela, sardina redonda y sardina peruana durante 1980, 1981, 1982 y 1983 en aguas ecuatorianas.

La información existente sobre huevos y larvas de peces en esta región es en general escasa; Ahlstrom (1971 ó 1972) estudió la distribución y abundancia de larvas de peces sobre una transecta en los 82°W.

Cajas e Hinostroza (1981), estudiaron la distribución de huevos y larvas de engráulidos y de *Opisthonema* en una zona del Golfo de Guayaquil. Peribonio, et al. (1981), registraron bajos valores de la biomasa total de huevos y larvas de peces en el Golfo de Guayaquil para el mes de Junio. Jiménez (1982) sugiere que existe una relación entre el patrón de distribución del fitoplancton y el de los huevos y larvas de peces, con valores máximos en el Golfo de Guayaquil y decrecientes hacia el océano abierto y hacia el norte de la Costa de Ecuador.

El presente trabajo analiza la distribución y abundancia de huevos y larvas de macarela y de algunos de los clupeidos que se registraron en el área comprendida entre la Costa ecuatoriana y los 82°W y entre 1° latitud norte y 3°20' de latitud sur.

## Características del área y condiciones oceanográficas de la región

La línea de costa de la región estudiada carece de irregularidades de gran complejidad, excepto en el Golfo de Guayaquil donde desemboca la gran cuenca del río Guayas, que establece una morfología típica estuarina con gran aporte de sedimentos sobre sus costas y su plataforma continental. La extensión de la plataforma es alrededor de 42 km con una profundidad promedio de 156 m en su borde externo. La plataforma es en general suave y amplia, excepto en Cabo San Lorenzo y Puntilla Santa Elena donde se presenta escarpada y angosta (Miró et al., 1976 y 1977).

La circulación superficial de gran escala que domina en la región es desde el Sureste, presentando un sistema frontal o Frente Ecuatorial que tiene características estacionales que han sido descritos en los aspectos hidrográficos por Wyrtki (1966), Wooster (1969), Stevenson et al. (1970), Enfield (1976) y Pak y Zaneveld (1974), entre otros autores.

El Frente Ecuatorial es una región que separa las aguas tropicales superficiales ($T > 23^{\circ}C$, $S < 33.5$ o/oo) de las aguas subtropicales superficiales modificadas ($T < 21^{\circ}C$, $S > 34.59$ o/oo).

El Frente se manifiesta claramente en aguas ecuatorianas durante el invierno austral, cuando se intensifican los vientos del Sureste y el flujo hacia el Noroeste de la corriente fría y salina de Humboldt se hace más fuerte; presentando una distribución zonal que está comprendida desde aproximadamente los $2^{o}$S sobre la Costa ecuatoriana hacia el noroeste. Durante el verano debido al debilitamiento de los vientos del sur y al flujo de las aguas cálidas y menos salinas del Norte, el Frente se manifiesta débil y replegado al Sur, sobre la Costa peruana. Desplazamientos anormales de este flujo cálido del norte han determinado las localizaciones extremas del Frente hacia el Sur y la ocurrencia del fenómeno conocido como "El Niño" el cual origina cambios drásticos en la productividad biológica del Frente (Jiménez, 1982, 1983).

Pak y Zaneveld (1973, 1974) han sugerido que una extensión de las aguas frías y salinas de la Subcorriente Ecuatorial hacia el Este de las Islas Galápagos, determinaría un aporte permanente de agua fría a la región del Frente Ecuatorial, mientras que la Corriente Humboldt contribuiría con aportes de agua fría en forma estacional.

Con relación a los aspectos biológicos del Frente Ecuatorial, algunos trabajos han sido publicados con referencia a la producción primaria, fitoplancton y zooplancton. Caben citarse los trabajos de Jiménez (1976, 1978) quien ha encontrado que los valores bajos de clorofila a (0.2 $mg/m^3$/día) registrados al norte estuvieron relacionados con las aguas tropicales cálidas, mientras que los valores altos de clorofila (6 - 2 $mg/m^3$) y de productividad (6.8-42.1 mg $C/m^3$/día) (20-50 $mg/m^3$) detectados al sur estuvieron asociados con el límite de las aguas más frías del Frente Ecuatorial. La descripción de las características planctónicas asociadas al Frente son presentadas con mayores detalles en el trabajo de Jiménez (1983) en esta misma reunión.

## METODOS

Las muestras de ictioplancton analizadas en el presente trabajo han sido colectadas durante los cruceros de evaluación de recursos pesqueros pelágicos y prospección acústica, realizados a bordo del B/I "Tohallí" del Instituto Nacional de Pesca y en un barco de pesca perteneciente a la empresa privada; debido a ello no presentan una regularidad espacio-temporal.

En el año de 1980, durante los meses de septiembre y octubre, se muestrearon los 100 m superiores de la columna de agua, donde la profundidad del fondo marino lo permitió, usando la red Hensen de 300 u de malla.

En 1981 las colectas fueron realizadas en Febrero-Marzo y Agosto mediante arrastres oblicuos entre la superficie y los 140 m de profundidad utilizando redes cilíndricas-cónicas de 500 u de malla tipo CALCOFI.

En Junio de 1982, se muestreó a bordo del Barco Pesquero "Pacífico" con red Hensen de 300 u en la zona costera del Golfo de Guayaquil.

En Noviembre-Diciembre de 1982, se realizaron arrastres oblicuos desde los 140 m de profundidad, utilizando redes Bongo de 500 u de malla.

Se analizó además parte de la información obtenida en Enero de 1983, donde se siguió una metodología similar a la empleada en Noviembre-Diciembre 1982.

Con excepción de la red Hensen, en todas las redes se colocaron flujómetros para determinar el volumen del agua filtrada en cada arrastre. Todos los arrastres fueron llevados a una cantidad estandar de agua filtrada por unidad de profundidad, ajustando así el número de huevos y larvas obtenidos, a número de especímenes bajo 10 $m^2$ de área de superficie del mar (Kramer et. al.,1972; Smith y Richardson, 1977).

Los huevos y las larvas de las diferentes especies fueron identificados y separados del total de la muestra. En la identificación se siguieron las descripciones de Kramer (1960) para macarela, y las de Santander y Castillo (1972), Houde y Fore (1973) y Balbontín y Garretón (1977) para los clupeidos.

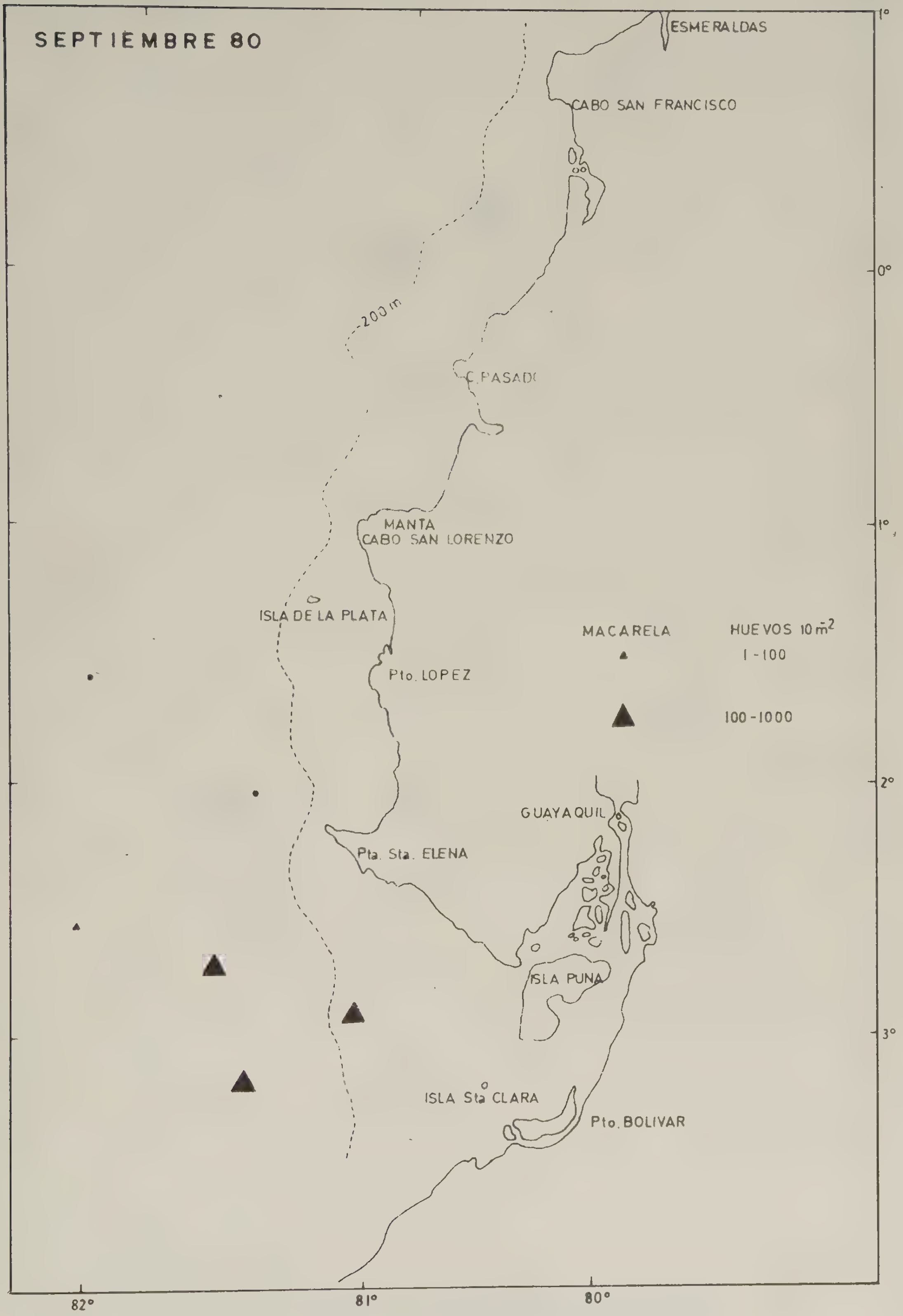
SEPTIEMBRE 80
ESMERALDAS
CABO SAN FRANCISCO
200 m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
MACARELA
HUEVOS 10 m⁻²
▲ 1 - 100
▲ 100 - 1000
GUAYAQUIL
Pta. Sta. ELENA
ISLA PUNA
ISLA Sta CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. I DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN SEPTIEMBRE DE 1980.

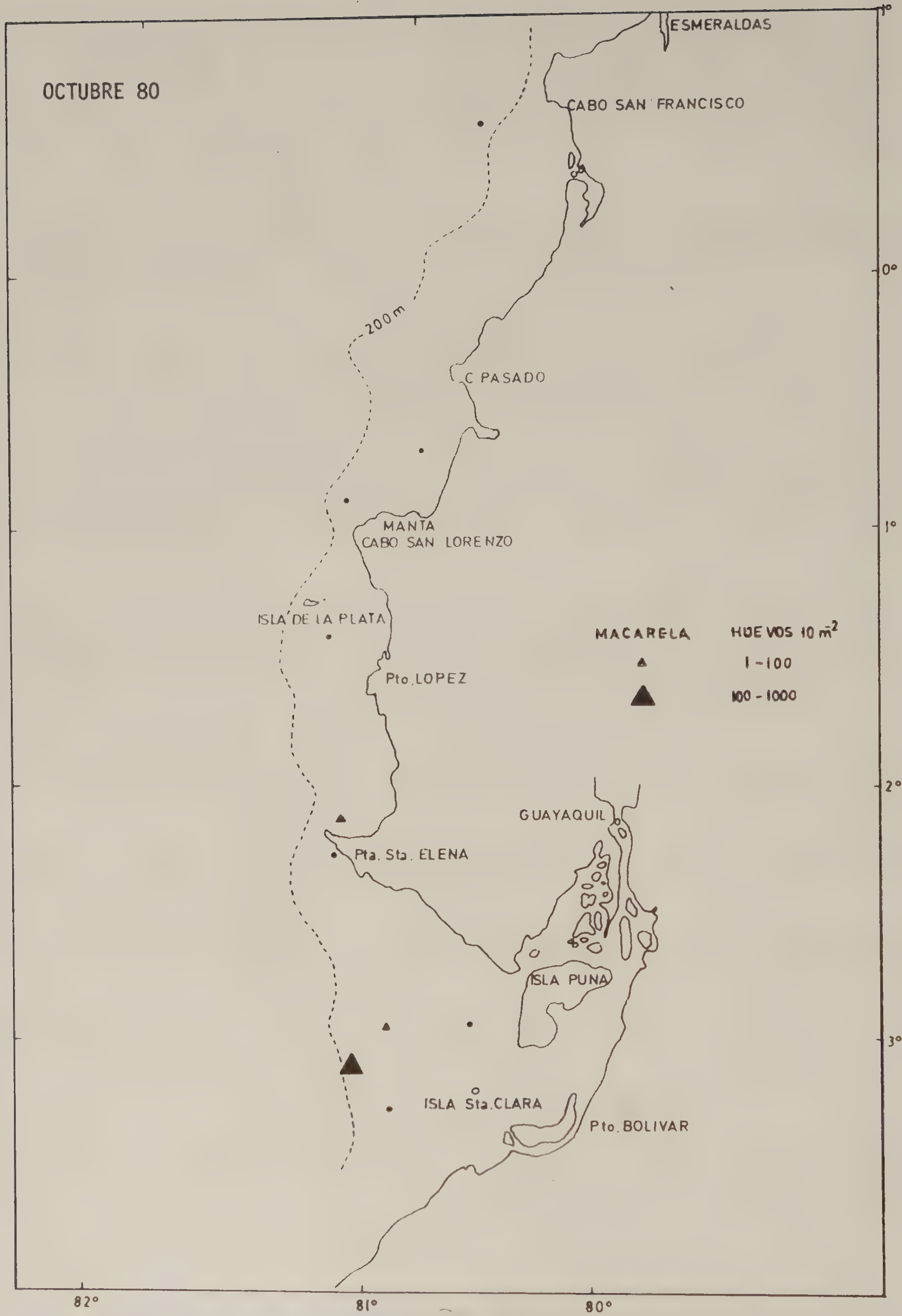
OCTUBRE 80
ESMERALDAS
CABO SAN FRANCISCO
200 m
C PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
MACARELA
HUEVOS 10 $m^{-2}$
▲ 1 - 100
▲ 100 - 1000
GUAYAQUIL
Pta. Sta. ELENA
ISLA PUNA
ISLA Sta. CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 2 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN OCTUBRE 1980.

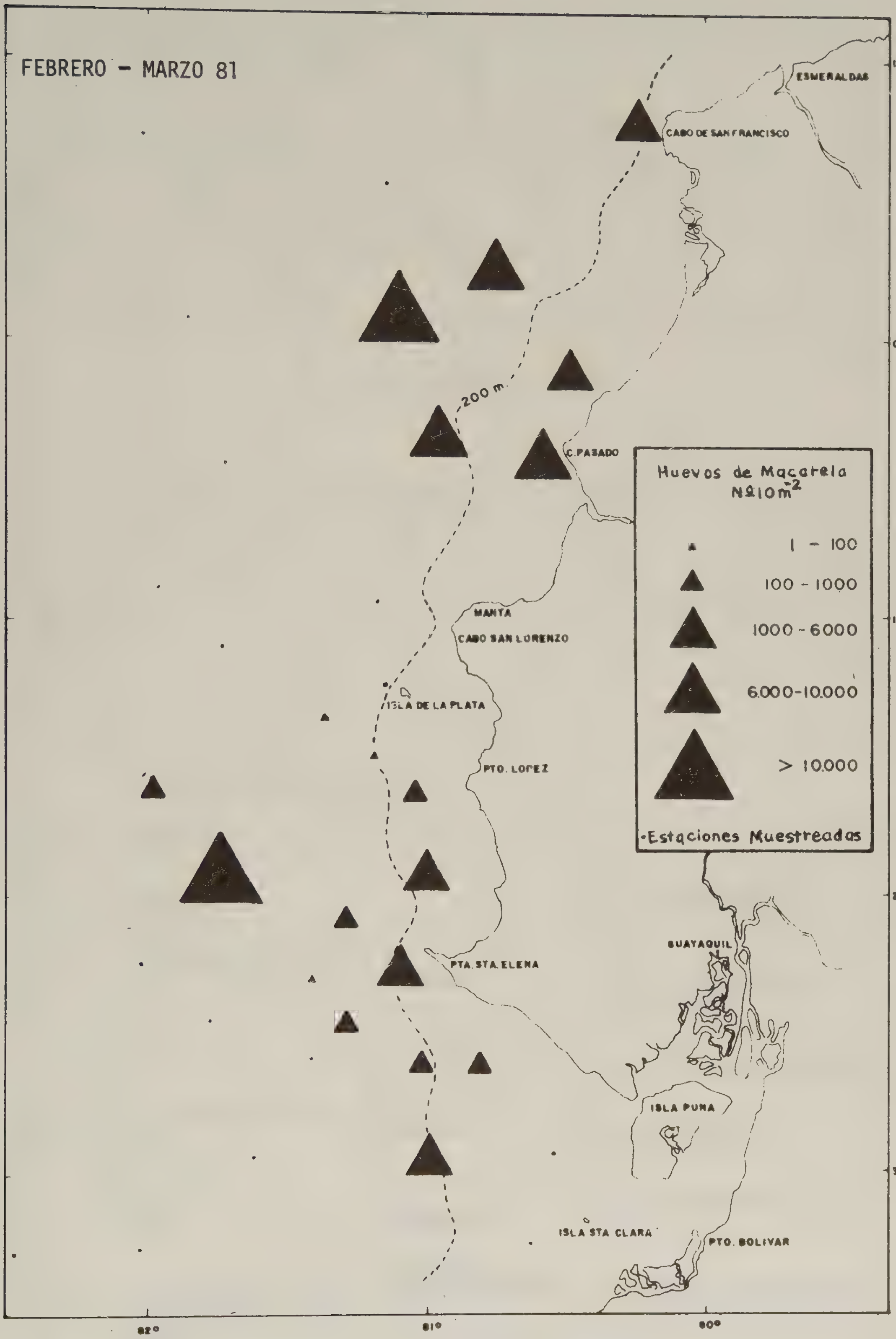
FEBRERO - MARZO 81
ESMERALDAS
CABO DE SAN FRANCISCO
200 m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
PTO. LOPEZ
PTA. STA. ELENA
GUAYAQUIL
ISLA PUNA
ISLA STA CLARA
PTO. BOLIVAR
Huevos de Macarela
Nº10m$^{-2}$
1 - 100
100 - 1000
1000 - 6000
6000-10.000
> 10.000
·Estaciones Muestreadas
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 3 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN FEBRERO Y MARZO DE 1981.

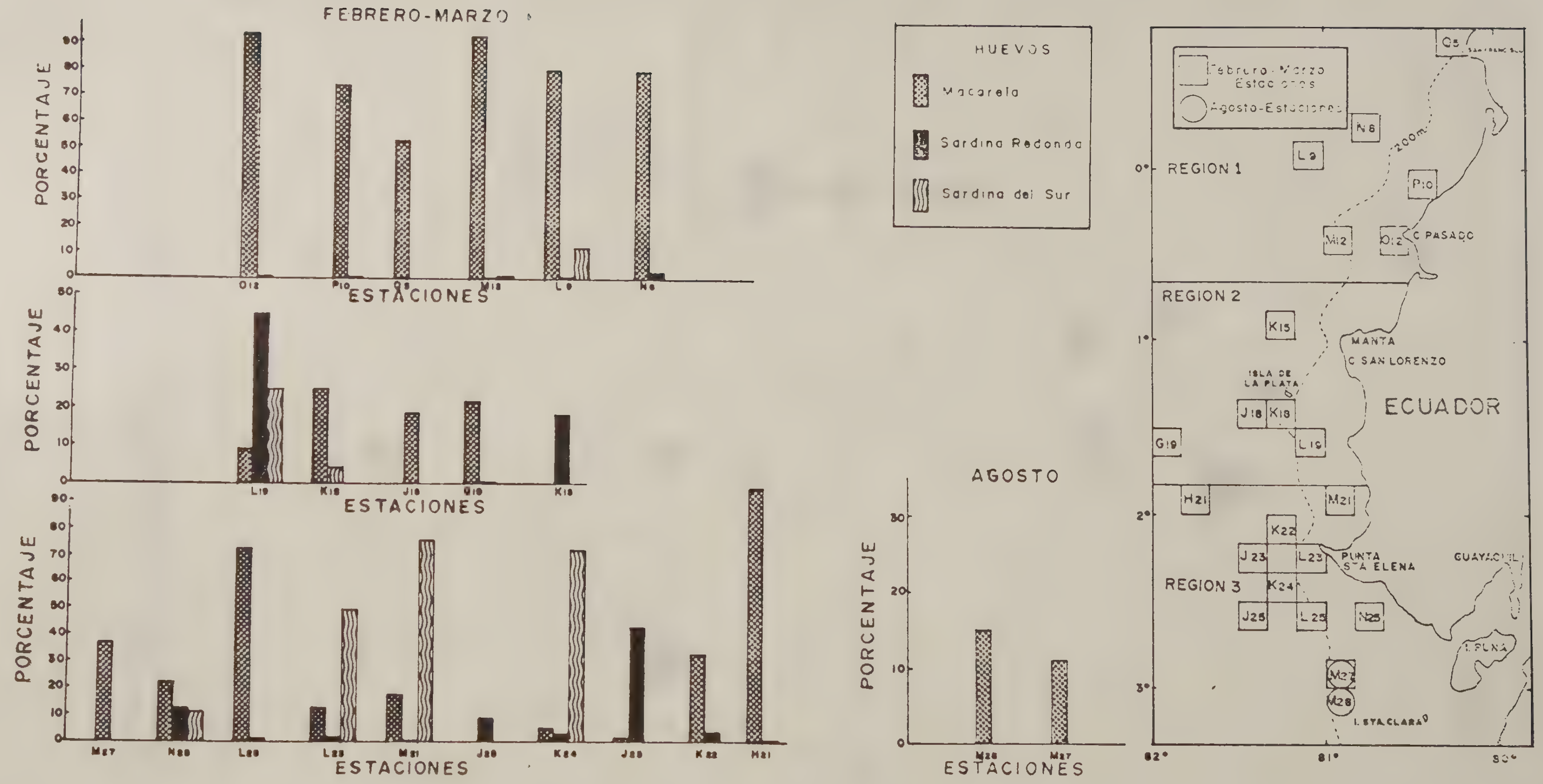

Fig. 4. ABUNDANCIA RELATIVA DE HUEVOS DE MACARELA, SARDINA REDONDA Y SARDINA DEL SUR EN FEBRERO MARZO Y AGOSTO DE 1981. EXPRESADO EN TERMINOS DE PORCENTAJE DEL TOTAL DE HUEVOS.

La mayoría de las larvas denominadas en este trabajo como "otros clupeidos" han presentado características morfológicas y merísticas similares a aquellas señaladas para la sardina del sur. No obstante, en algunas estaciones se registraron además, larvas con número de miómeros inferiores (47-49) que fueron correspondientes al número de vértebras de ciertas especies de *Ophistonema* existentes en la región.

Los primeros estadíos de estas especies son poco conocidos y en vista de que los organismos que han predominado en las muestras presentan tallas muy pequeñas, el contaje de miómeros no ha sido muy útil para diferenciarlos y agruparlos como "otros clupeidos".

Las larvas de macarela y de "otros clupeidos" han sido clasificados por tallas para Febrero-Marzo de 1981, utilizando la longitud comprendida entre el hocico y el borde de la nortoconda.

Para el presente trabajo se han analizado en total 7 cruceros con un total de 115 muestras.

## RESULTADOS

### Macarela

En septiembre y octubre de 1980, los huevos de macarela estuvieron distribuidos hacia los 3°S desde el margen continental hacia el océano abierto y sus concentraciones fueron menores a 1 000 huevos 10 $m^{-2}$ (Figs. 1, 2).

En febrero-marzo de 1981, constituyó un período de intenso desove, observándose dos áreas con importantes concentraciones de huevos; la una estuvo ubicada a los 0° y la otra entre los 3°S y al norte de Punta de Santa Elena.

La amplitud del desove abarcó hasta 60 millas fuera de la costa, concentrándose sobre la zona del talud en la región del sur (Fig. 3).

Las máximas concentraciones registradas ($>$10 000 huevos 10 $m^{-2}$) se obtuvieron hacia el noroeste de las concentraciones, más allá de la plataforma continental.

Las elevadas densidades de huevos obtenidos durante esta época han evidenciado la importancia de la macarela en la región. Representó el 50.47% del total de huevos capturados (Tabla 1) y fue la especie predominante en las muestras de la región del norte, donde constituyó entre el 50-90% del total de huevos colectados por esta estación (Fig. 4).

TABLA 1.-ABUNDANCIA RELATIVA DE HUEVOS Y LARVAS DE MACARELA, SARDINA REDONDA, SARDINA DEL SUR Y DE "OTROS CLUPEIDOS" EN FEBRERO-MARZO Y AGOSTO DE 1981

| | HUEVOS (Porcentaje del total) | | | | LARVAS (Porcentaje del total) | | | |
|---|---|---|---|---|---|---|---|---|
| CRUCEROS 1981 | Macarela | Sardina redonda | Sardina del sur | Otros huevos | Macarela | Sardina redonda | "Otros clupeidos" | "Otras larvas" |
| Febrero-Marzo | 50.47 | 2.22 | 22.63 | 24.67 | 20.21 | 0.80 | 27.40 | 51.60 |
| Agosto | 1.61 | | | 98.39 | 0.40 | | 0.93 | 98.67 |

French (1982), a partir de la información obtenida a través de las bitácoras de pesca encontró que esta especie fue el recurso más abundante capturado por la flota en 1981. En agosto del mismo año, los registros de huevos han sido escasos, con concentraciones inferiores a los 1 000 huevos 10 $m^{-2}$ (Fig. 5). Su distribución estuvo restringida hacia los 3°S y consituyeron apenas un 1.61% en el porcentaje del total de huevos colectados durante el crucero (Tabla 1).

En 1982, no se detectaron huevos de macarela para el mes de junio y en noviembre-diciembre, concentraciones entre 100-1000 huevos 10 $m^{-2}$ fueron comunmente encontradas en una zona ubicada frente al Golfo de Guayaquil, al norte de los 3°S (Fig. 6).

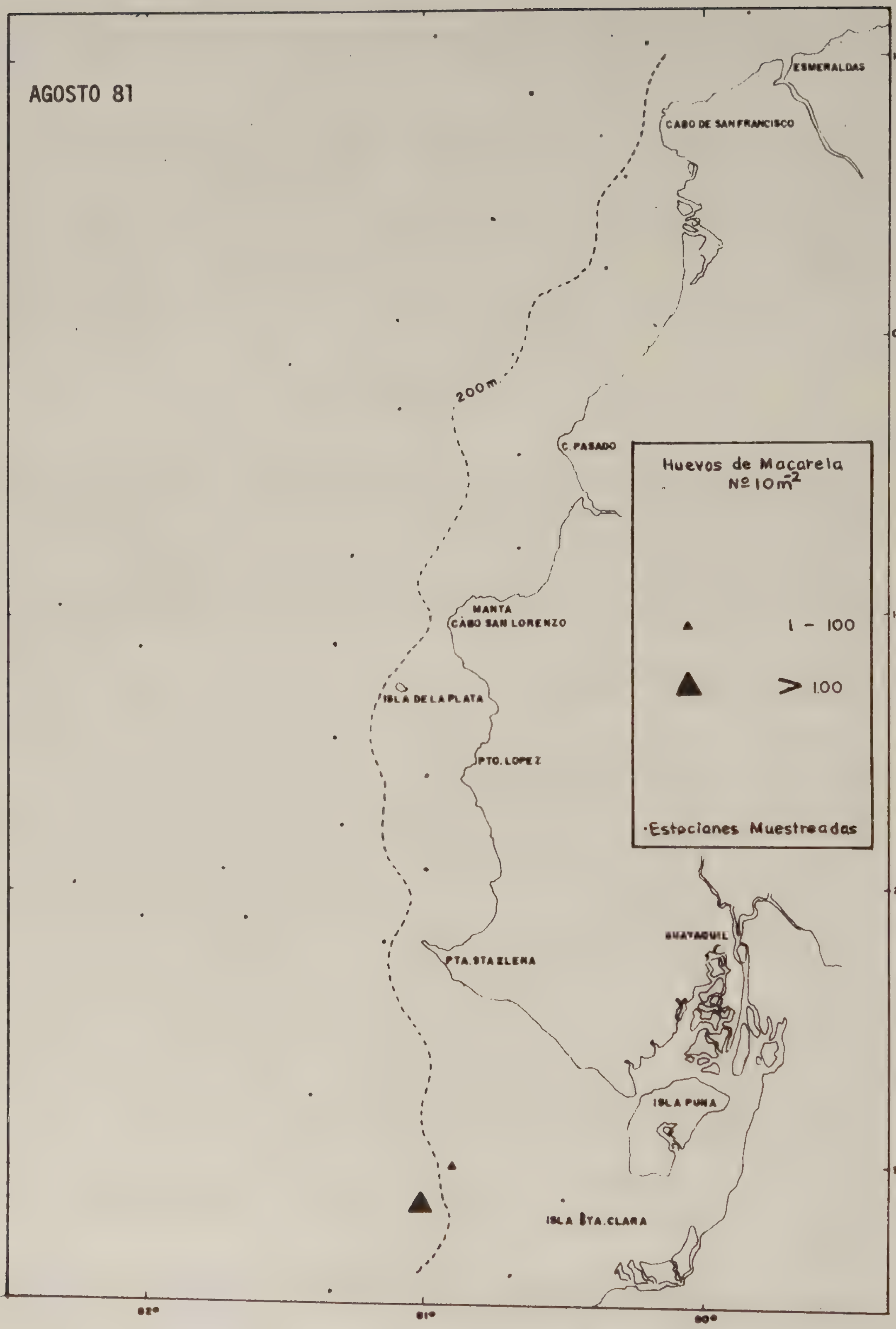
AGOSTO 81
ESMERALDAS
CABO DE SAN FRANCISCO
200m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
PTO. LOPEZ
PTA. STA ELENA
GUAYAQUIL
ISLA PUNA
ISLA STA. CLARA
Huevos de Macarela
Nº 10m²
▲ 1 - 100
▲ > 100
· Estaciones Muestreadas
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 5 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA
IN AGOSTO DE 1981.

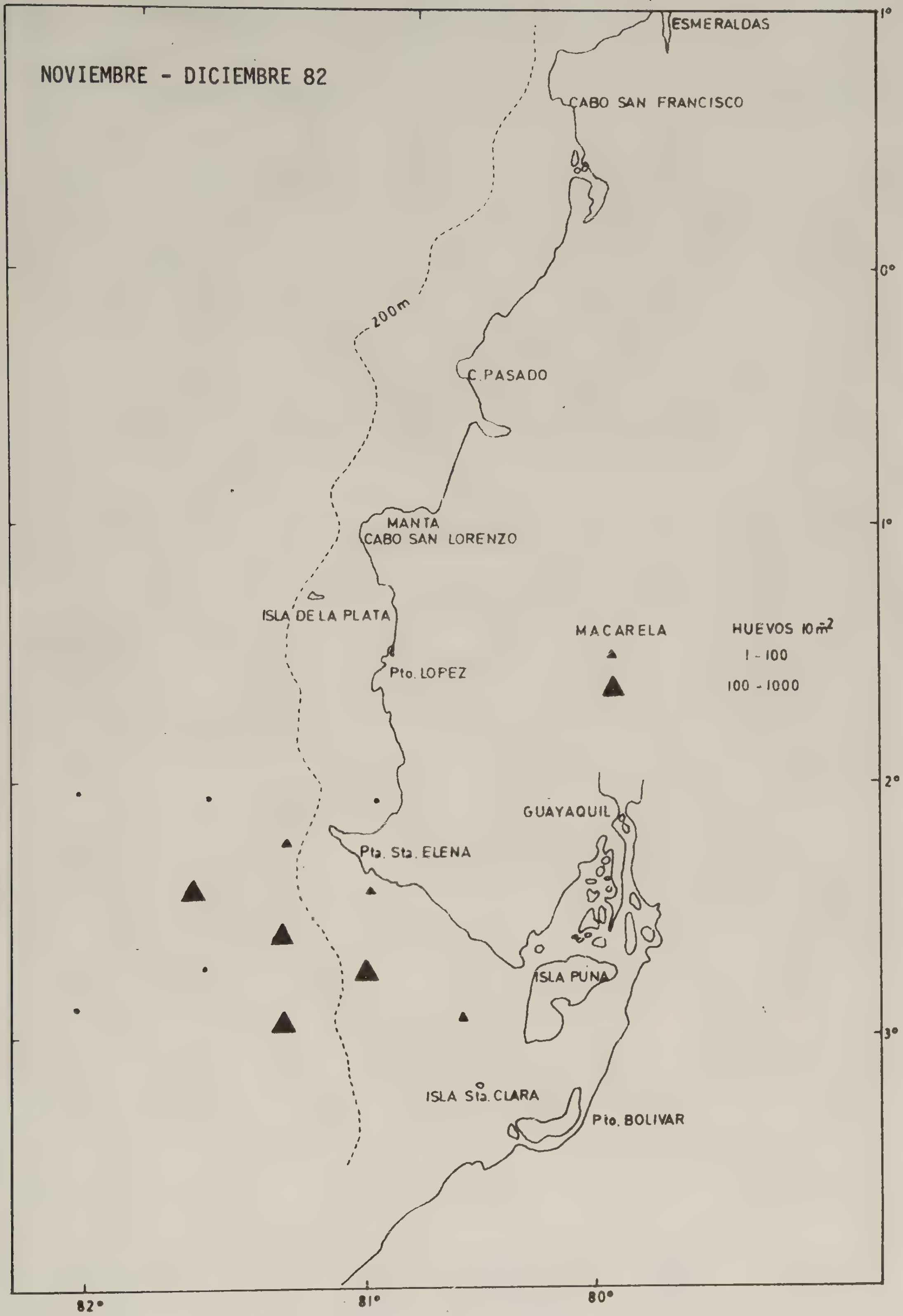
NOVIEMBRE - DICIEMBRE 82
ESMERALDAS
CABO SAN FRANCISCO
200m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
MACARELA
HUEVOS 10 m$^{-2}$
▲ 1 - 100
▲ 100 - 1000
GUAYAQUIL
Pta. Sta. ELENA
ISLA PUNA
ISLA Sta. CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 6 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN NOVIEMBRE-DICIEMBRE DE 1982.

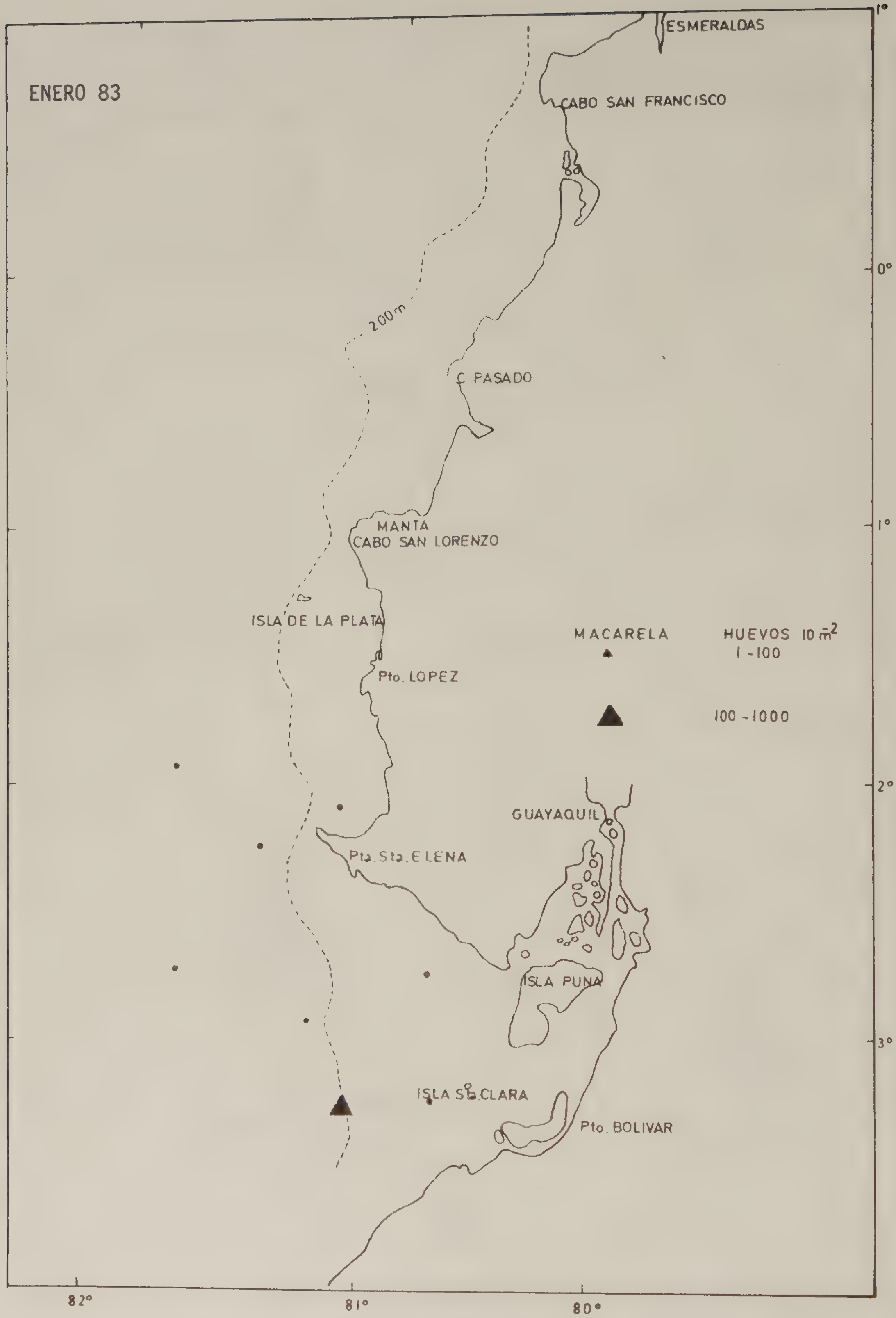
ENERO 83
ESMERALDAS
CABO SAN FRANCISCO
200 m
C PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
MACARELA
HUEVOS 10 m$^{-2}$
▲ 1 - 100
▲ 100 - 1000
GUAYAQUIL
Pta. Sta. ELENA
ISLA PUNA
ISLA Sta. CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 7 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN ENERO DE 1983.

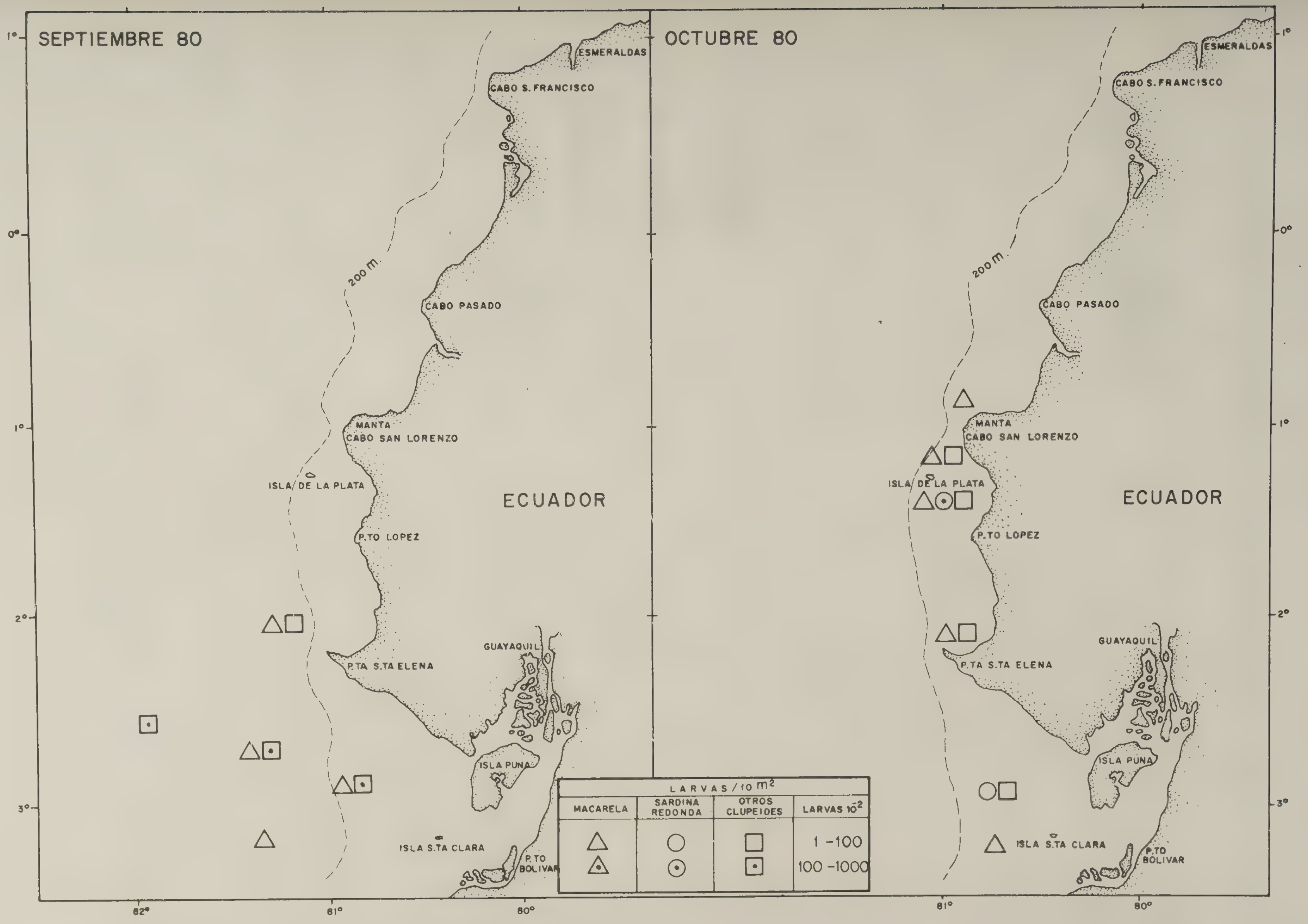
SEPTIEMBRE 80
OCTUBRE 80
ECUADOR
ESMERALDAS
CABO S. FRANCISCO
CABO PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
P.TO LOPEZ
P.TA S.TA ELENA
GUAYAQUIL
ISLA PUNA
ISLA S.TA CLARA
P.TO BOLIVAR
200 m.
1°
0°
1°
2°
3°
82°
81°
80°
LARVAS /10 m²
MACARELA
SARDINA REDONDA
OTROS CLUPEIDES
LARVAS 10²
1 -100
100 -1000

Fig. 8 DISTRIBUCION Y ABUNDANCIA DE LARVAS DE MACARELA, SARDINA REDONDA Y OTROS CLUPEIDOS EN SEPTIEMBRE Y OCTUBRE DE 1980.

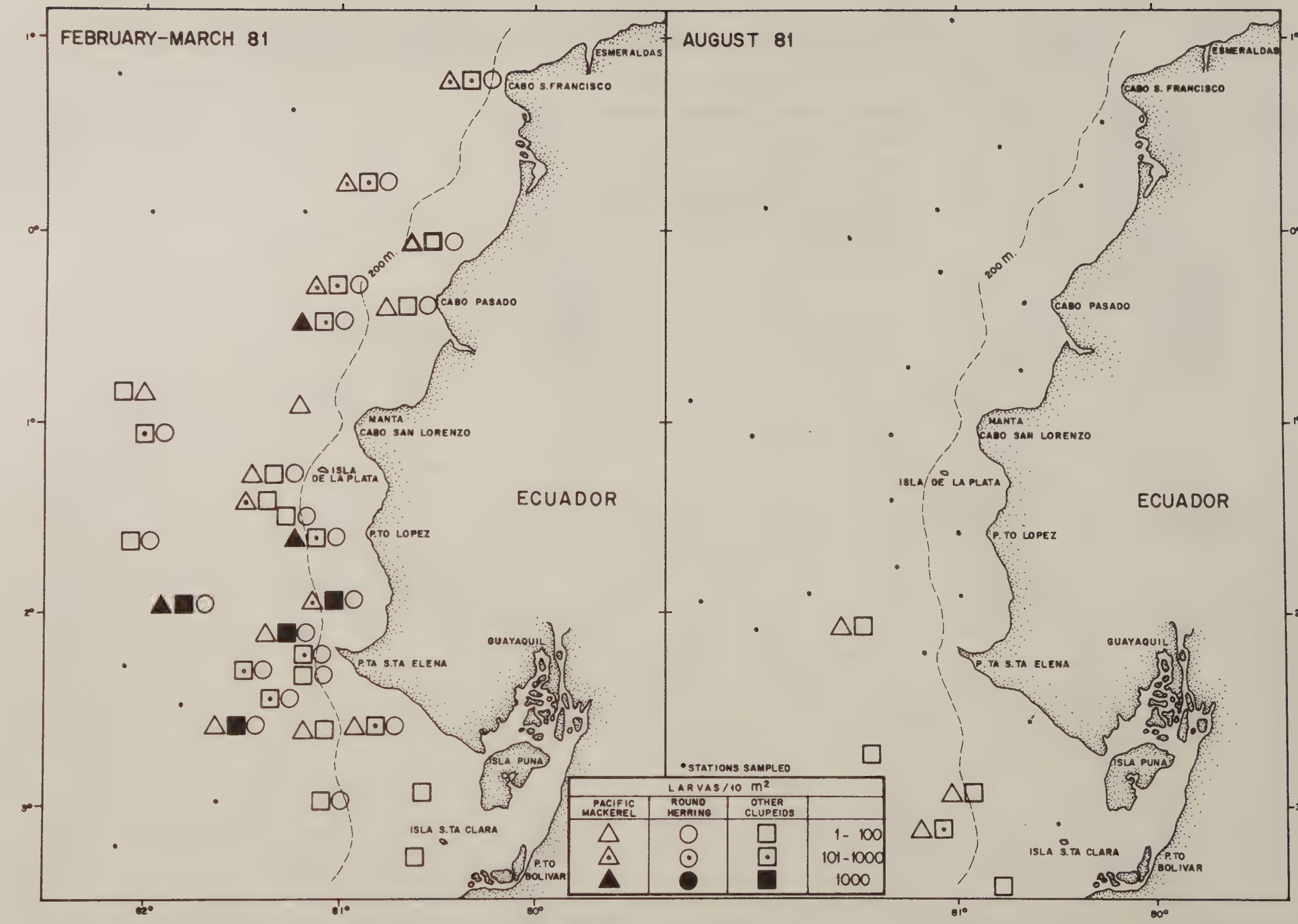
FEBRUARY-MARCH 81
AUGUST 81
ECUADOR
ESMERALDAS
CABO S. FRANCISCO
CABO PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
P.TO LOPEZ
P.TA S.TA ELENA
GUAYAQUIL
ISLA PUNA
ISLA S.TA CLARA
P.TO BOLIVAR
200 m.
1°
0°
1°
2°
3°
82°
81°
80°
• STATIONS SAMPLED
LARVAS/10 m²
PACIFIC MACKEREL
ROUND HERRING
OTHER CLUPEIDS
1- 100
101-1000
1000

Fig. 9. DISTRIBUCION Y ABUNDANCIA DE LARVAS DE MACARELA, SARDINA REDONDA Y OTROS CLUPEIDOS EN FEBRERO-MARZO Y AGOSTO DE 1981

En Enero de 1983, huevos de esta especie ($<$1 000 huevos 10 $m^{-2}$) han sido detectados en una sola estación localizada al sur de los 3°S (Fig. 7).

La distribución de las larvas estuvo en relación con las de las áreas de reproducción, pero su agrupamiento fue menor.

Concentraciones muy bajas ($<$100 larvas 10 $m^{-2}$) fueron registradas durante los meses de septiembre y octubre 1980, agosto de 1981 y enero de 1983 y más altas ($>$1000 larvas 10 $m^{-2}$) durante febrero-marzo 1981 y noviembre-diciembre 1982 (Figs. 8-11).

En Febrero-Marzo representaron un 20.21% del total de larvas capturadas, mientras que en agosto del mismo año su porcentaje se limita a un 0.40% (Tabla 1).

Las tallas más comunes en la población larval de febrero-marzo fueron aquellas comprendidas entre los 2.50 mm -3.49 mm (Tabla 2) correspondientes a los organismos en fase de primera alimentación (Hunter y Kimbrel, 1980).

En los análisis de larvas, también se ha manifestado la predominancia de esta especie hacia el Norte de Santa Elena durante febrero-marzo (Fig. 12).

## Sardina Redonda

Huevos y larvas de sardina redonda han sido obtenidos únicamente en los arrastres de octubre de 1980, febrero-marzo de 1981 y noviembre-diciembre de 1982.

En octubre de 1980, el desove fue registrado entre los 1°S y Pta. Santa Elena (Fig. 13) mientras que en febrero-marzo y noviembre-diciembre la zona situada alrededor de Pta. Santa Elena constituyó el principal centro de desove (Figs. 14 y 15).

En febrero-marzo, la distribución del desove se extendió hasta los 0° en un patrón más continuo que el de macarela (Fig. 14).

Los huevos generalmente se encontraron en concentraciones inferiores a 1 000 huevos 10 $m^{-2}$, aunque en noviembre-diciembre de 1982 se obtuvieron registros superiores a los 1 000 huevos 10 $m^{-2}$.

Las larvas concurrieron en las mismas áreas de distribución de las larvas de macarela en concentraciones inferiores a 100 larvas 10 $m^{-2}$ (Figs. 8, 9, 10). Solo en noviembre-diciembre de 1982 se obtuvieron valores superiores a 100 larvas 10 $m^{-2}$ (Fig. 10).

La sardina redonda fue en general la especie que se mostró menos abundante en la región; en febrero-marzo representó un 2.22% del total de huevos capturados y un 0.80% del total de larvas.

## Sardina del Sur

Huevos de Sardina del sur han sido registrados únicamente en septiembre de 1980 y marzo de 1981.

En septiembre el desove fue pobre ($<$1 000 huevos 10 $m^{-2}$) y estuvo limitado a 3 registros detectados sobre los 3°S frente al Golfo de Guayaquil (Fig. 16).

En febrero-marzo de 1981, el desove fue intenso ($>$6 000 huevos 10 $m^{-2}$), en el área costera alrededor de Pta. Santa Elena y escaso hacia los 0°S fuera de la Costa (Fig. 17). Ello coincide con lo expresado por French y Menz (1982), de que en las capturas de enero a abril, la Sardina del sur presentó en el Golfo de Guayaquil una distribución más costera que la macarela.

Constituyó el 22.63% del total de huevos colectados durante esta época (Tabla 1).

## Otros Clupeidos

Larvas de clupeidos han sido colectadas en todos los meses monitoreados. Concurrieron en las mismas áreas de distribución de las larvas de macarela durante 1980 y 1981 (Figs. 8, 9) y en 1982 y 1983 su distribución fue particularmente costera (Figs. 10 y 11).

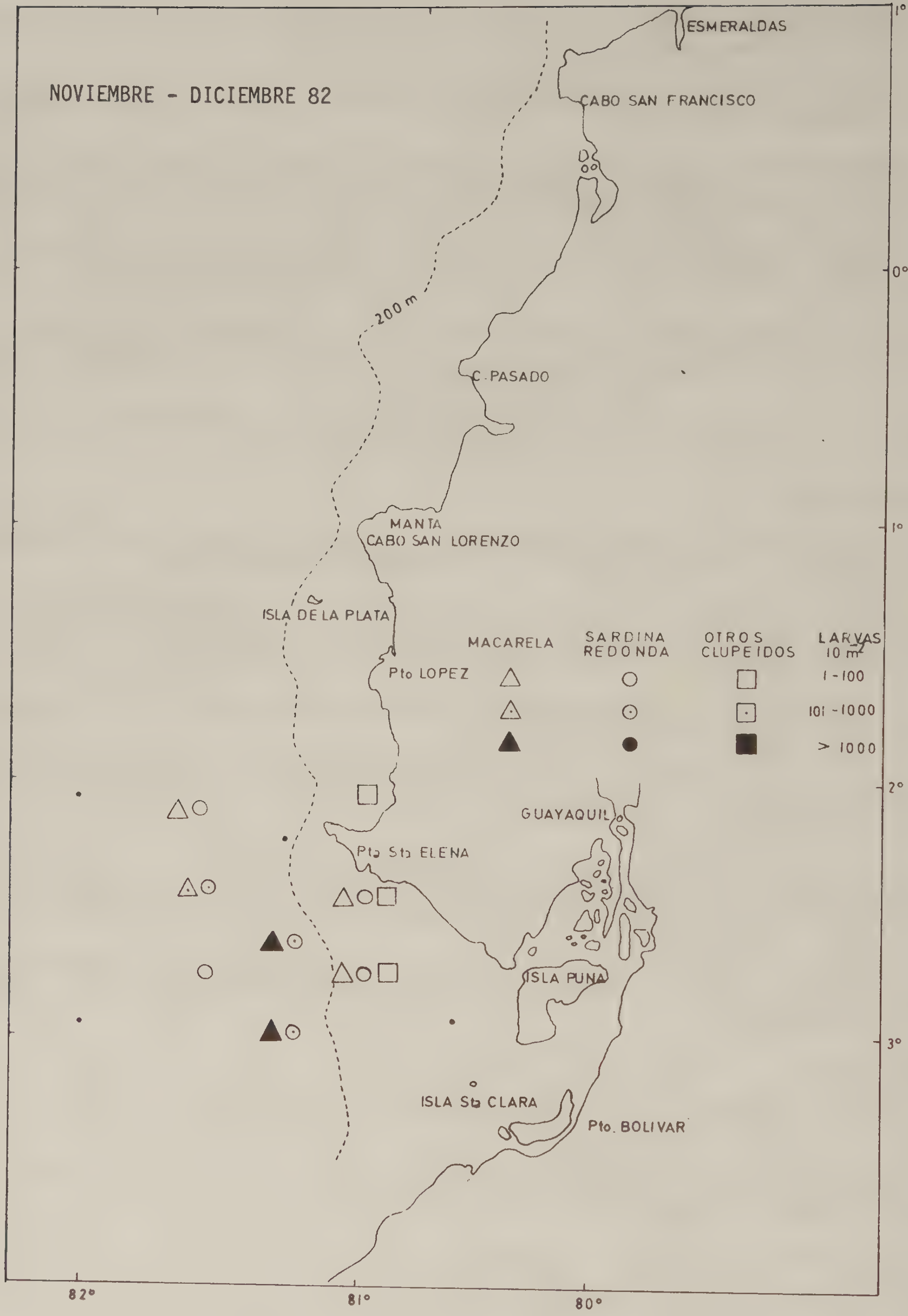
NOVIEMBRE - DICIEMBRE 82
ESMERALDAS
CABO SAN FRANCISCO
200 m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto LOPEZ
GUAYAQUIL
Pta Sta ELENA
ISLA PUNA
ISLA Sta CLARA
Pto. BOLIVAR
MACARELA
SARDINA REDONDA
OTROS CLUPEIDOS
LARVAS 10 m²
1 - 100
101 - 1000
> 1000
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 10 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE MACARELA EN ENERO DE 1983.

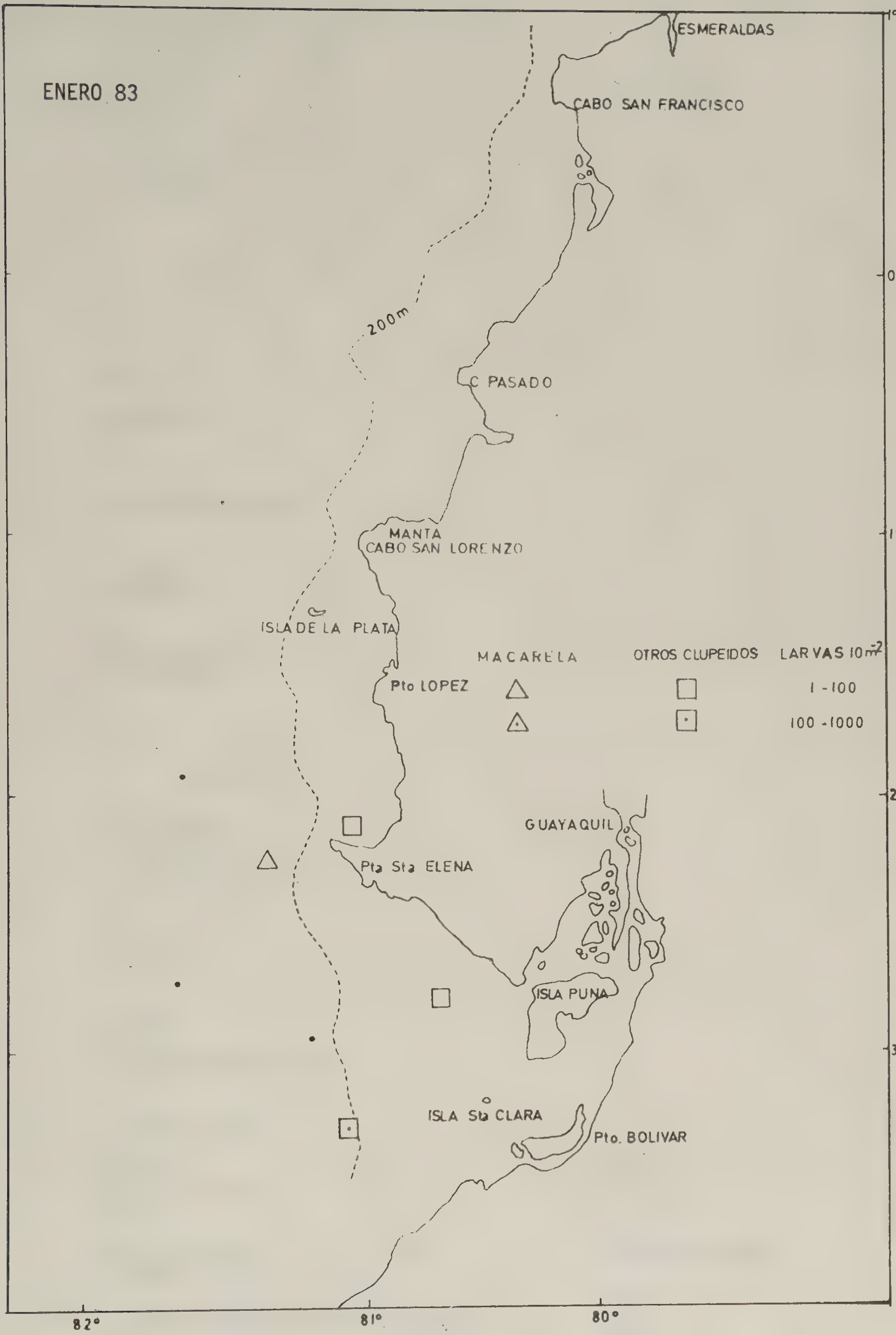
ENERO 83
ESMERALDAS
CABO SAN FRANCISCO
200m
C PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto LOPEZ
MACARELA
OTROS CLUPEIDOS
LARVAS 10m⁻²
1 -100
100 -1000
GUAYAQUIL
Pta Sta ELENA
ISLA PUNA
ISLA Sta CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 11 DISTRIBUCION Y ABUNDANCIA DE LARVAS DE MACARELA Y OTROS CLUPEIDOS EN ENERO DE 1983.

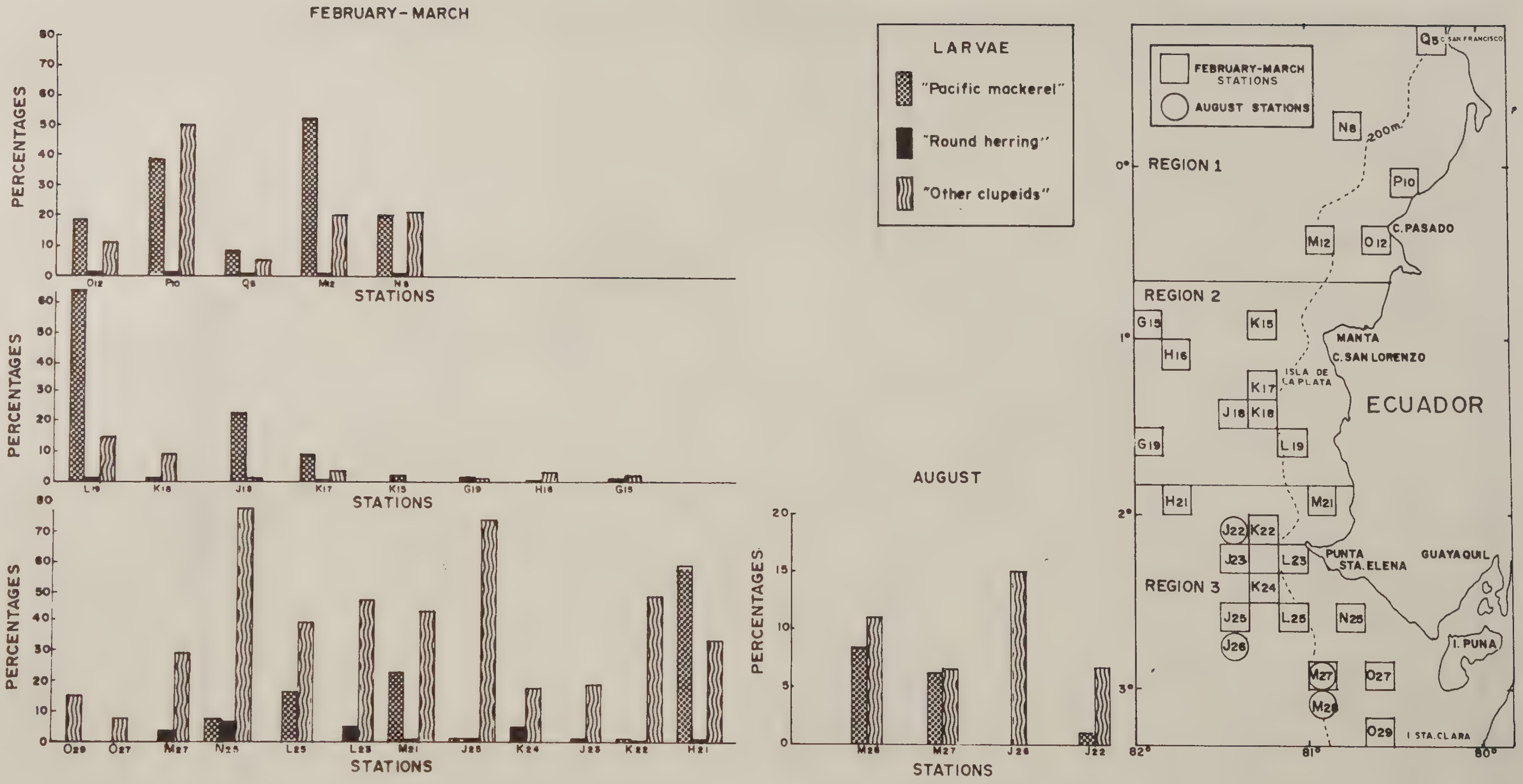

Fig. 12 ABUNDANCIA RELATIVA DE LARVAS DE MACARELA, SARDINA REDONDA Y OTROS CLUPEIODOS EN FEBRERO-MARZO Y AGOSTO DE 1981 EXPRESADA EN PORCENTAJE DEL TOTAL DE HUEVOS COLECTADOS

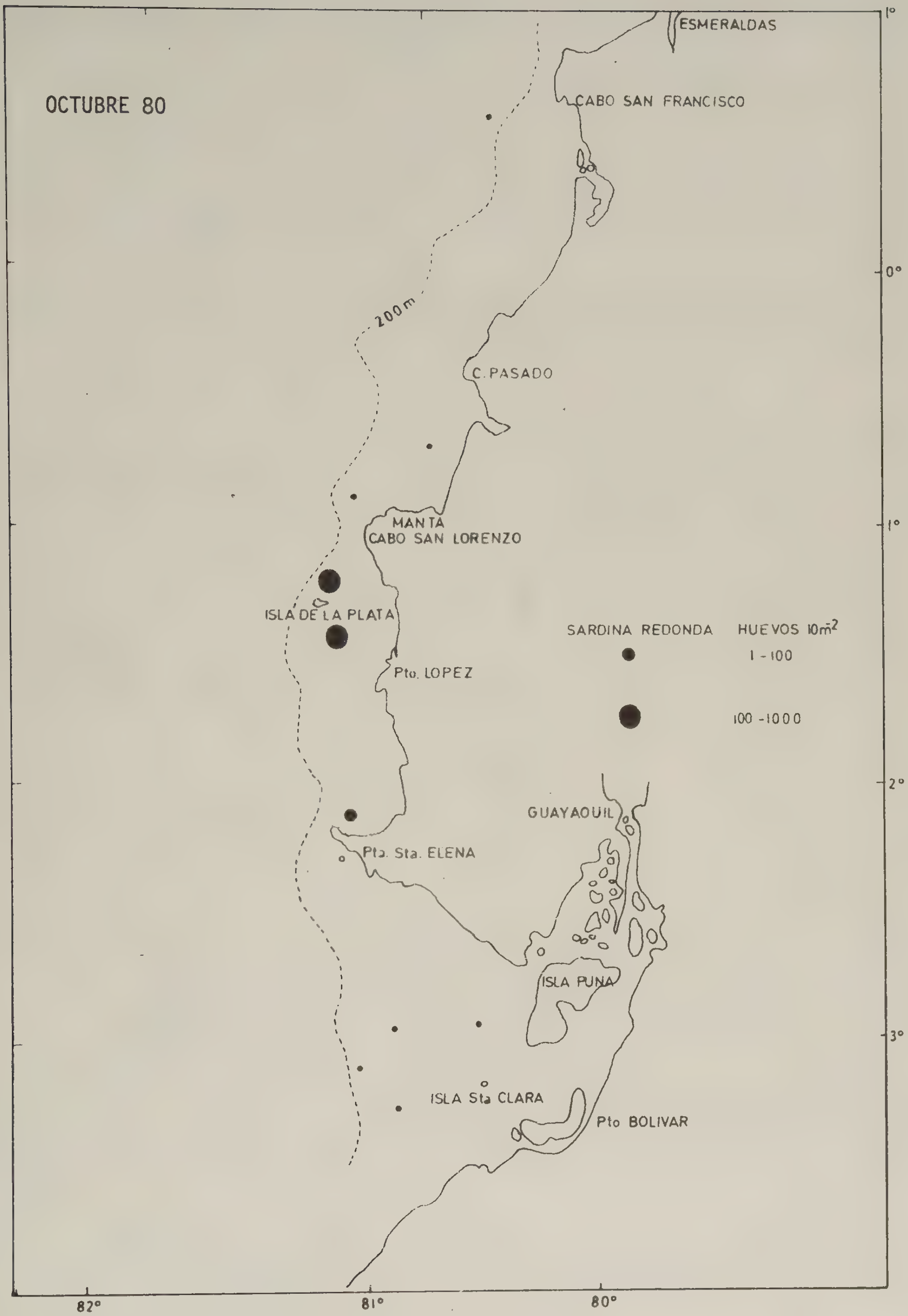
OCTUBRE 80
ESMERALDAS
CABO SAN FRANCISCO
200 m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
SARDINA REDONDA HUEVOS 10m$^{-2}$
1 - 100
100 - 1000
GUAYAQUIL
Pta. Sta. ELENA
ISLA PUNA
ISLA Sta CLARA
Pto BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 13 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE SARDINA REDONDA EN OCTUBRE DE 1980.

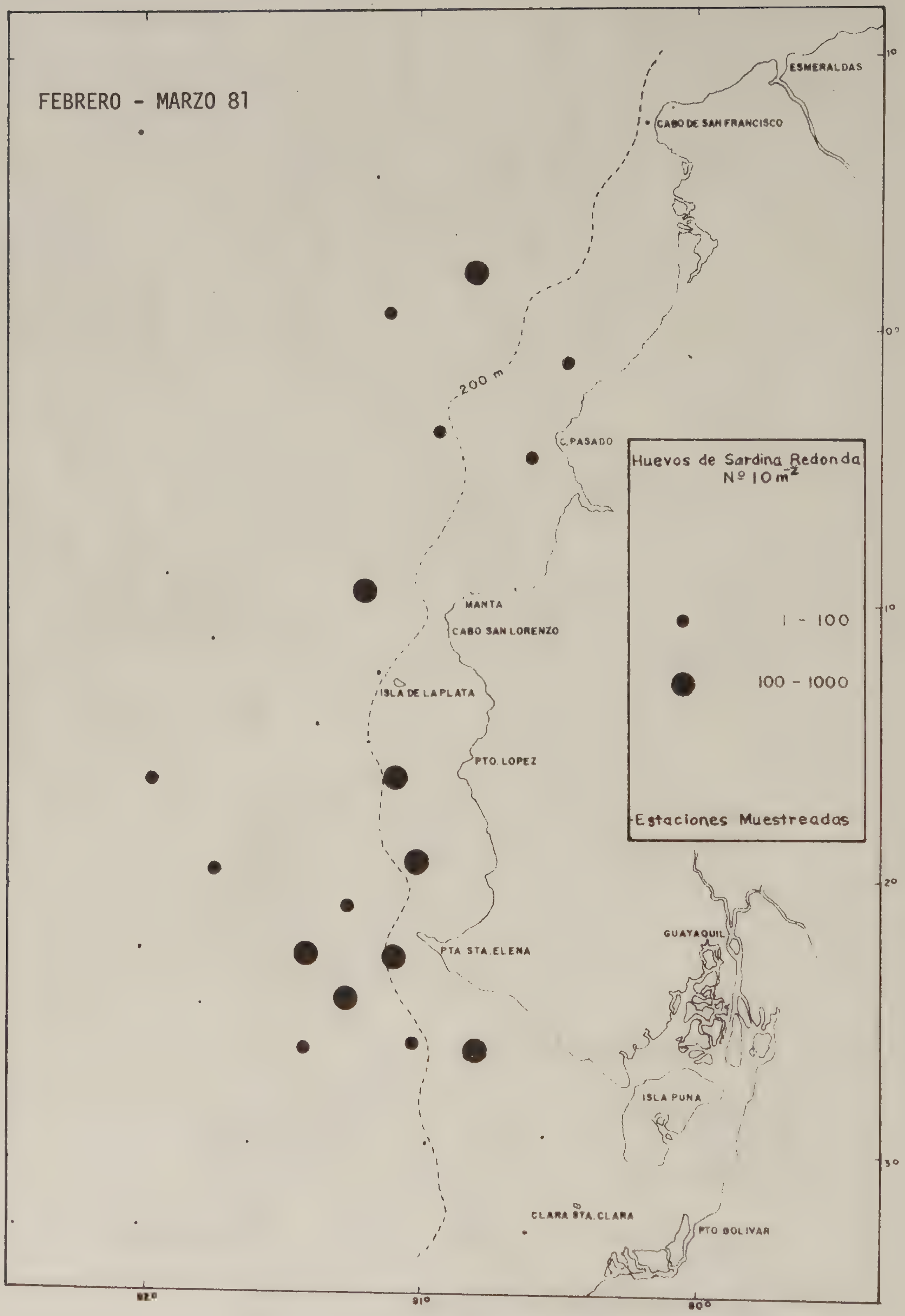
FEBRERO - MARZO 81
ESMERALDAS
CABO DE SAN FRANCISCO
200 m
C. PASADO
Huevos de Sardina Redonda
Nº 10 m$^{-2}$
1 - 100
100 - 1000
Estaciones Muestreadas
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
PTO. LOPEZ
PTA STA. ELENA
GUAYAQUIL
ISLA PUNA
CLARA STA. CLARA
PTO BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 14 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE SARDINA REDONDA EN FEBRERO Y MARZO 1981.

Durante septiembre, octubre, agosto, noviembre y diciembre, estas larvas fueron menos abundantes ($<$1 000 larvas 10 m$^{-2}$) mientras que en Febrero-Marzo alcanzaron sus mayores densidades ($>$1 000 larvas 10 m$^{-2}$) y fueron las larvas más abundantes de la región sur (Fig. 12). Su porcentaje fue del 27.40% en la captura total.

## DISCUSION

Marcadas diferencias han sido detectadas en el desove de las tres especies entre Agosto, que corresponde a la época fría, y Febrero-Marzo, correspondiente a la época cálida. Al parecer, el desove en general fue abundante y extenso durante los meses de la época cálida y pobre durante la época fría.

French y Menz (1982) analizando los registros de las capturas de macarela y sardina del sur han encontrado que estas especies extienden su rango de distribución hacia el norte a partir de Octubre, alcanzando su máxima extensión en los meses de Febrero y Marzo.

TABLA 2.-LARVAS DE MACARELA, FEBRERO-MARZO 1981*

| Clase Long.standar (mm) | ESTACION | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T81-107 | T81-109 | T81-117 | T81-118 | T81-120 | T81-123 | T81-124 | T81-126 | T81-128 | T81-130 | T81-135 | T81-139 | T81-141 | T81-145 | T81-150 | TOTAL |
| 1.50-2.49 | 5 | | 17 | 230 | 29 | 1 | - | | 20 | 4 | 67 | 71 | 110 | | | 554 |
| 2.50-3.49 | 6 | 2 | 269 | 495 | 420 | 62 | 7 | 5 | 9 | 45 | 19 | 224 | 119 | | | 1682 |
| 3.50-4.49 | | 1 | 117 | 38 | 398 | 13 | - | 1 | 2 | 6 | | 232 | 7 | 2 | | 717 |
| 4.50-5.49 | | | 4 | 3 | 85 | - | 13 | | | | | 45 | | 4 | | 154 |
| 5.50-6.49 | 1 | | | | 15 | 1 | 7 | | 2 | | | | | 2 | | 28 |
| 6.50-7.49 | | | | | | | 3 | | | | | | | | 1 | 4 |
| 7.50-8.49 | | | | | | | 1 | | | | | | | | | 1 |
| 8.50-9.49 | | | | | | | | | | | | | | | | |
| 9.50-10.49 | | | | | | | | | | | | | | | | |
| 10.50-11.49 | | | | | | | | | | | | | | | | |
| 11.50-12.49 | | | | | | | | | | | | | | | | |
| 12.50-13.49 | | | | | | | | | | | | | | | | |
| 13.50-14.49 | | | | | | | | | | | | | | | | |
| 14.50-15.49 | | | | | | | | | | | | | | | | |
| 15.50-16.49 | | | | | | | | | | | | | | | | |
| 16.50-17.49 | | | | | | | | | | | | | | | 1 | 1 |
| 17.50-18.49 | | | | | | | | | | | | | | | 1 | 1 |
| Total | 12 | 3 | 307 | 766 | 947 | 77 | 31 | 6 | 33 | 55 | 86 | 572 | 236 | 8 | 3 | 3142 |

* Los números están expresados en Nº de larvas por arrastre.

La extensión en la distribución de estas especies hacia el norte se ha manifestado con más amplitud en el desove, dicho comportamiento estaría relacionado con los requerimientos reproductivos de las especies. Las variaciones espacio-temporales observadas en los desoves mostraron una estrecha relación con los cambios estacionales que se produjeron en el océano.

La distribución de las isotermas en la columna de agua muestran la máxima estratificación en Febrero-Marzo, encontrándose un fuerte gradiente (25$^{o}$C - 17$^{o}$C) muy superficial que se extendió desde los 1$^{o}$N hasta los 3$^{o}$S sobre los 50 metros superiores (Fig. 18a) (Cucalón, 1981). Evidentemente, existió en esta época aporte efectivo de aguas frías ricas en nutrientes, desde las capas subsuperficiales hacia la zona eufótica que favorecieron la producción primaria. Elevados valores de clorofila a en superficie ($>$5 mg/m$^{3}$) han sido registrados a lo largo de toda la costa durante Febrero-Marzo de 1981 (Jiménez, 1983).

Las floraciones ("bloom") de *Mesodinium rubrum* (2.6 x 10$^{5}$ cell/litro) que fueron registradas también entre los 0$^{o}$ y 3$^{o}$S durante Febrero-Marzo de 1981 (Arcos, 1982) estuvieron relacionadas a las áreas de los máximos desoves.

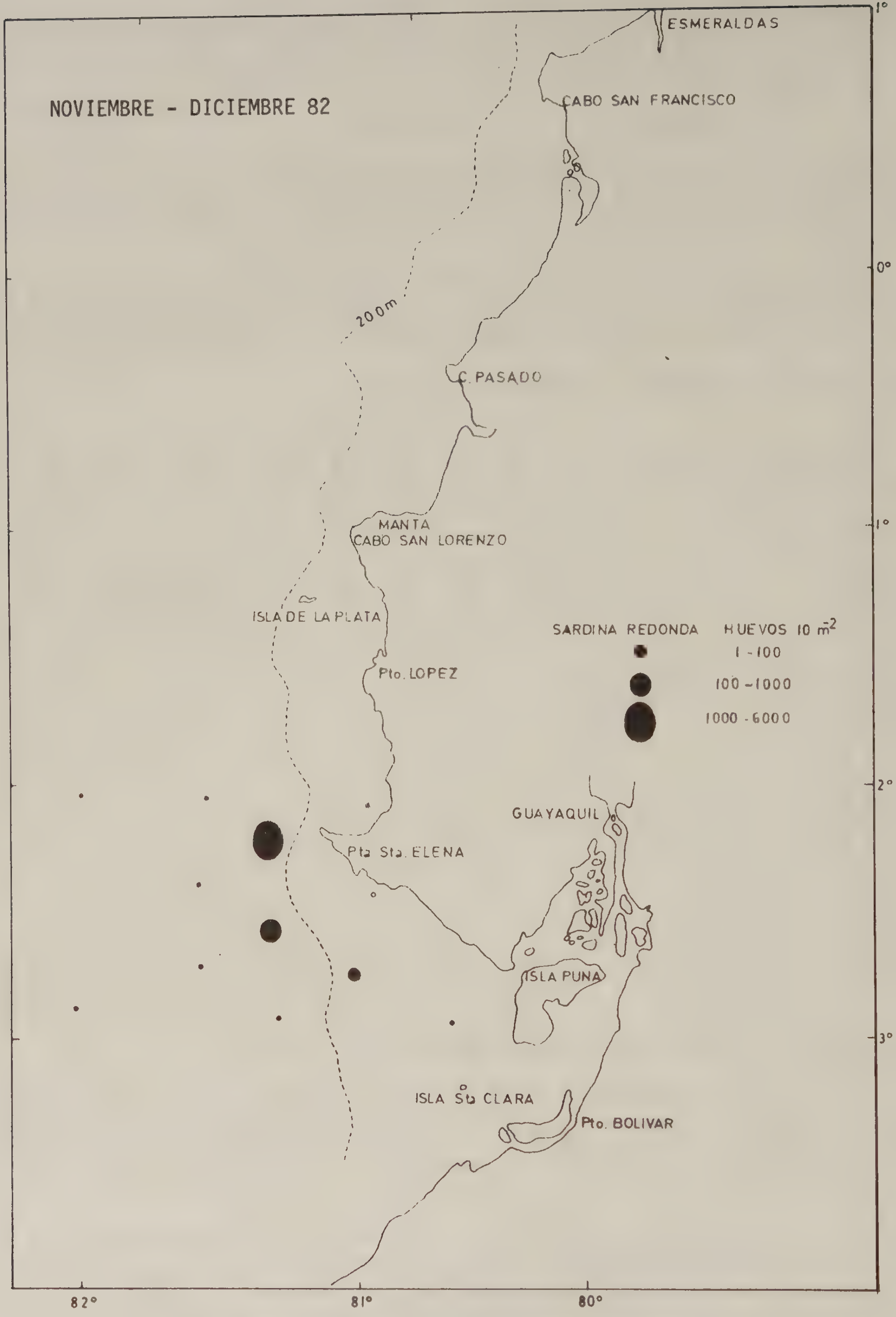
NOVIEMBRE - DICIEMBRE 82
ESMERALDAS
CABO SAN FRANCISCO
200m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto. LOPEZ
SARDINA REDONDA
HUEVOS 10 m$^{-2}$
1 - 100
100 - 1000
1000 - 6000
GUAYAQUIL
Pta Sta. ELENA
ISLA PUNA
ISLA Sta CLARA
Pto. BOLIVAR
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 15 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE SARDINA REDONDA EN NOVIEMBRE-DICIEMBRE DE 1982.

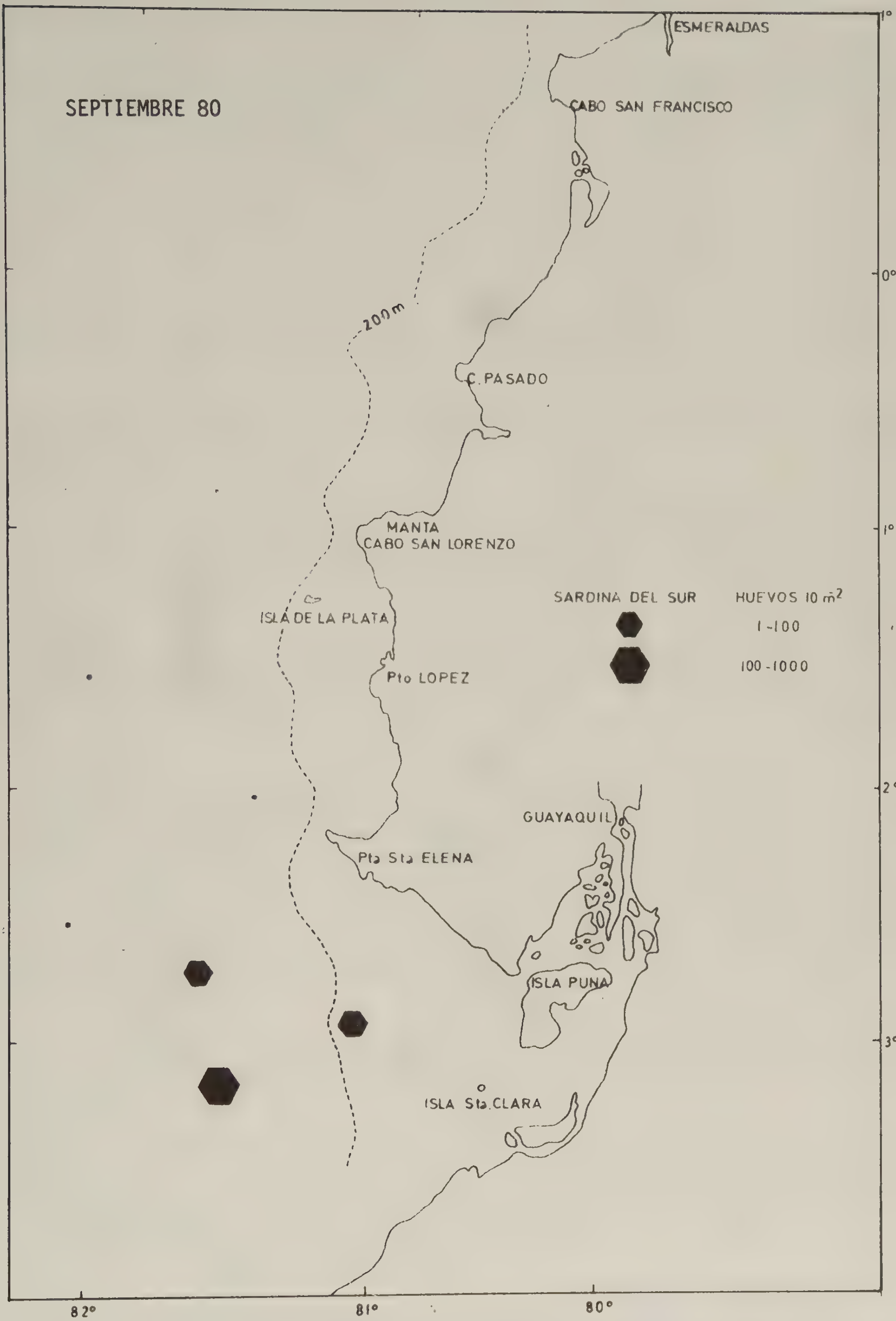
SEPTIEMBRE 80
ESMERALDAS
CABO SAN FRANCISCO
200 m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
Pto LOPEZ
GUAYAQUIL
Pta Sta ELENA
ISLA PUNA
ISLA Sta. CLARA
SARDINA DEL SUR
HUEVOS 10 m²
1 - 100
100 - 1000
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 16 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE SARDINA DEL SUR EN SEPTIEMBRE DE 1980.

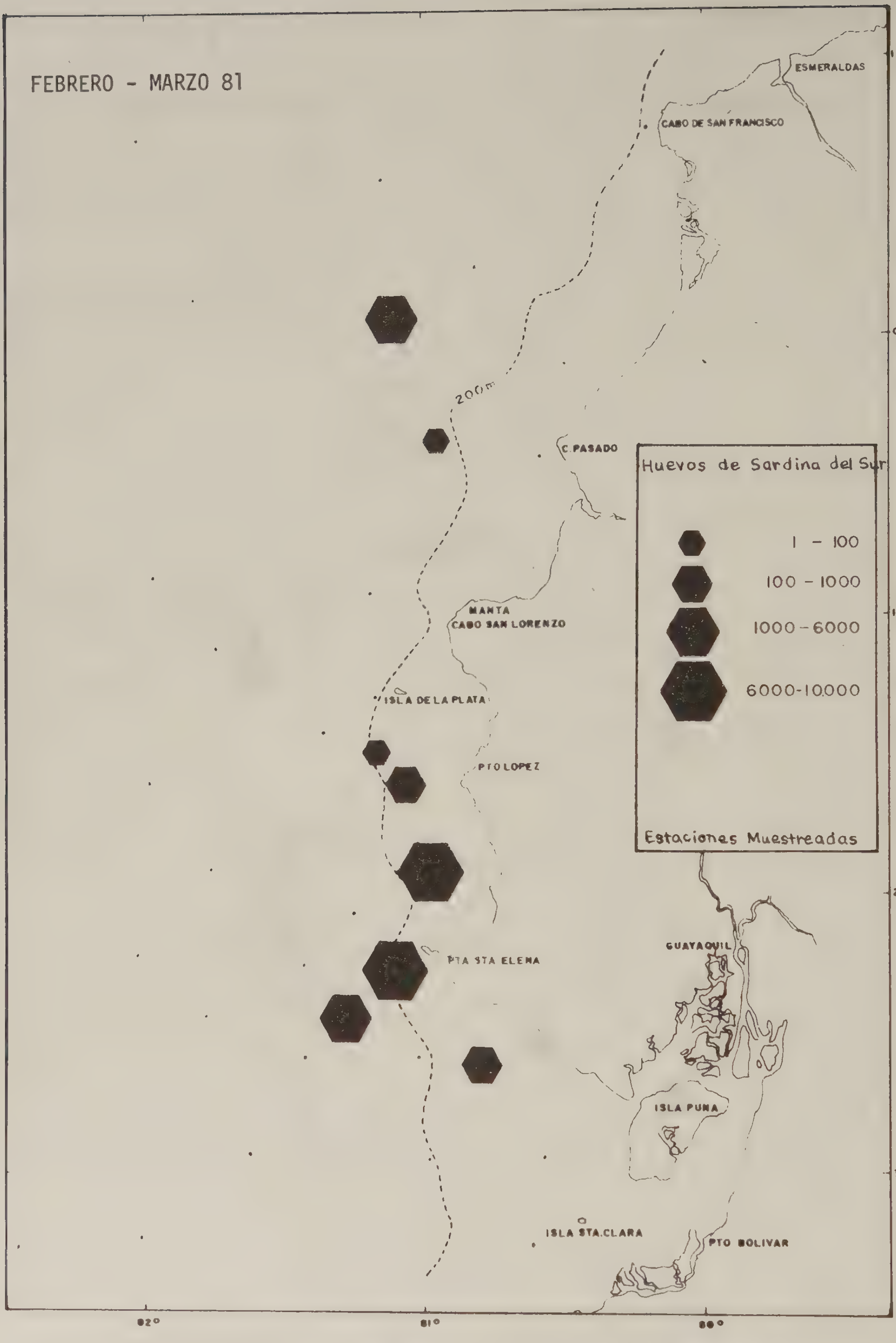
FEBRERO - MARZO 81
ESMERALDAS
CABO DE SAN FRANCISCO
200m
C. PASADO
MANTA
CABO SAN LORENZO
ISLA DE LA PLATA
PTO LOPEZ
PTA STA ELENA
GUAYAQUIL
ISLA PUNA
ISLA STA. CLARA
PTO BOLIVAR
Huevos de Sardina del Sur
1 - 100
100 - 1000
1000 - 6000
6000-10,000
Estaciones Muestreadas
1°
0°
1°
2°
3°
82°
81°
80°

Fig. 17 DISTRIBUCION Y ABUNDANCIA DE HUEVOS DE SARDINA DEL SUR EN FEBRERO-MARZO DE 1981.

En estos meses los desoves fueron abundantes y las mayores concentraciones de huevos estuvieron distribuidas entre los 0° y los 3°S a lo largo de la Costa ecuatoriana.

En Agosto de 1981, en cambio se detectó una capa homogénea de 25°C sobre los 30 metros superiores hacia los 0° y la formación del frente hacia el sur (Fig. 18 b) (Cucalón, 1981a). En este mes, el fuerte gradiente térmico vertical se observó a mayor profundidad y el aporte de aguas frías hacia las capas más superficiales estuvo limitado únicamente a la región del frente en un flujo hacia afuera de la costa.

Jiménez y Bonilla (1980), encontraron una elevada productividad en la región del Golfo de Guayaquil asociada con la formación del frente y el aporte de las aguas frías del sur.

En Agosto de 1981, los altos valores de clorofila a en superficie ($>0.5$ mgr/m$^3$) y las floraciones de *M. rubrum* estuvieron localizados hacia el Sur (Arcos, 1982). En este mes el desove fue pobre y restringido al sur del Frente Ecuatorial.

Evidentemente la estabilidad de la columna de agua ha sido la característica determinante para un abundante desove en estas especies, correspondiéndole al verano, la época principal de desove.

Lasker (1975), ha manifestado que existe una estrecha relación entre la estabilidad en la columna de agua, el tamaño y la agregación de las partículas alimenticias y la supervivencia larvaria y encontró que un ambiente costero menos turbulento fue el más favorable para la alimentación de las pequeñas larvas de anchoveta del norte en las costas de California.

Parrish et al. (1981), han manifestado que muchas de las especies de peces costeros presentan una estrategia reproductiva adaptada a las corrientes, desovando en áreas ubicadas hacia arriba del flujo de las corrientes en las épocas en donde existe un mayor transporte hacia la costa, que es donde se encuentra el alimento adecuado para la alimentación de las pequeñas larvas.

En nuestra región poco es conocido sobre la circulación costera y el transporte Ekman, pero del análisis de las propiedades físicas, químicas y biológicas del océano y de las condiciones ambientales de la región, parecería que en la época del verano, al decrecer la intensidad de los vientos del sureste y de la Corriente de Humboldt, se produce una mayor calma en el océano y el flujo hacia la costa prevalece, lo cual favorece la concentración costera del alimento. La extensión de la distribución de los huevos de *S. japonicus*, *E. teres* y *S. sagax* hacia el norte, y la concentración de sus larvas en la zona costera durante la época de los mayores desoves indicarían que estas especies manifestaron una estrategia similar en la región y que una buena supervivencia larvaria se esperaría para el año 1981.

En los meses de Noviembre-Diciembre de 1982 y Enero de 1983, coincidentes con el fenómeno "El Niño" que ocurrió en esta región, se observaron cambios muy particulares en el desove de estas especies.

En Noviembre-Diciembre, los huevos de macarela, que han sido generalmente los más abundantes en la región, se presentaron en concentraciones inferiores a los 1 000 huevos 10 m$^{-2}$ (Fig. 6), mientras que los huevos de sardina redonda, que generalmente han sido escasos en la región, presentaron las máximas concentraciones ($>$ 1 000 huevos 10 m$^{-2}$) de todos los cruceros analizados en este trabajo. No se registraron huevos de sardina del sur.

En Enero de 1983, cuando, según los análisis de madurez sexual de la macarela (Arriaga, comunicacion personal) se esperaba obtener registros de huevos de esta especie en el océano, se observó que los desoves estuvieron restringidos a una sola estación en un área localizada muy costera al sur del Golfo, donde coincidió con un único máximo de fitoplancton. Los huevos de las otras especies no fueron detectados en este mes.

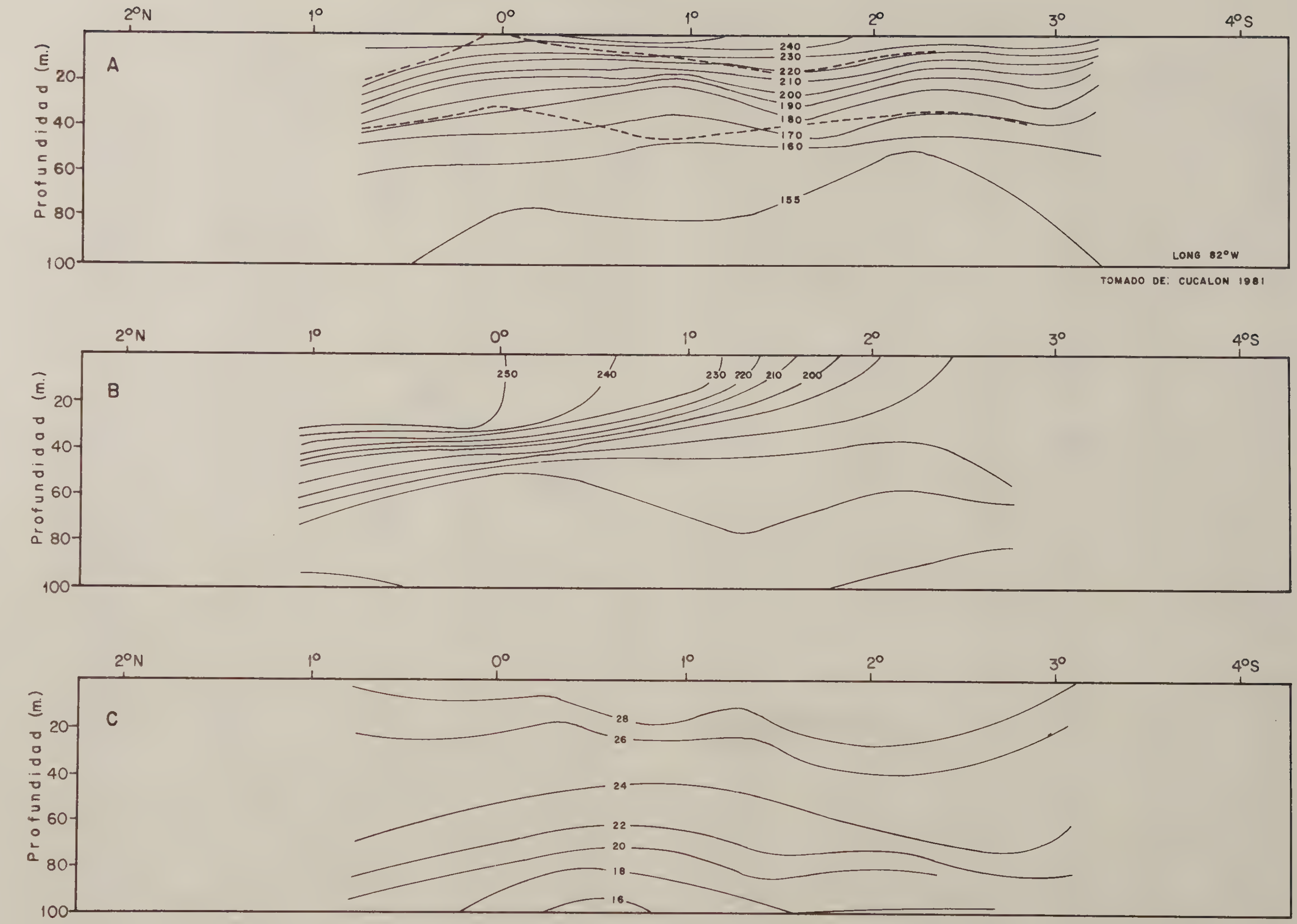

Fig. 18. DISTRIBUCION DE LAS ISOTERMAS ($^{0}$C) SOBRE LOS 100 m. SUPERIORES DE LA COLUMNA DE AGUA EN, 1a FEBRERO-MARZO 1981, 1b AGOSTO 1981, 1c FEBRERO 1983.

El análisis de la distribución de las isotermas sobre los 100 metros superiores en la línea 82$^{o}$W, durante Febrero de 1983 ha revelado que las condiciones en este verano han sido muy diferentes a las del verano de 1981, se detectó la penetración de las aguas cálidas hacia los estratos subsuperficiales, con la isoterma de 26$^{o}$C distribuida a los 40 metros de profundidad (Fig. 18 c). Ello sugeriría que una mala supervivencia larvaria se espera para el año 1983.

El análisis de la distribución y abundancia del desove de cada una de las especies en particular ha indicado:

- La abundancia de la macarela en la región y su carácter circuntropical. Sus huevos fueron capturados en todas las encuestas y presentó el rango de mayor distribución.

- La escasa abundancia de sardina redonda y su mayor vinculación con aguas cálidas. Las mayores concentraciones de sus huevos han sido registrados en Noviembre-Diciembre, 1982, durante "El Niño".

- El carácter más subtropical de la sardina del sur. Los huevos estuvieron presentes únicamente en Septiembre de 1980 y Febrero-Marzo de 1981, cuando existieron aportes superficiales o subsuperficiales de aguas frías en la región.

## AGRADECIMIENTO

Deseo dejar constancia de mi agradecimiento a las personas que colaboraron en la recolección y separación de las muestras, la elaboración de los gráficos, y la corrección y el tipeado del manuscrito, las mismas que de una u otra manera han hecho posible su presentación. Especial reconocimiento al Doctor Roberto Jiménez S., Director del Instituto Nacional de Pesca, por el apoyo y estimulo proporcionado a los estudios del Ictioplancton en el Ecuador.

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*SOUTH EAST PACIFIC - PACIFICO SUDORIENTAL*

# EL AMBIENTE MARINO Y LAS FLUCTUACIONES DE LAS PRINCIPALES POBLACIONES PELAGICAS DE LA COSTA PERUANA

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Lima
Perū

## Summary

The large changes which occur in the 0-500 m layer and particularly the upper mixed layer are presented, which play important roles in the currents, coastal upwelling, mixing processes and both vertical and horizontal thermal gradients. Emphasis is given to seasonal variations, and processes occuring in abnormally warm or cool periods and the responses to these changes by the major fishery resources such as anchoveta (*Engraulis ringens*); sardines (*Sardinops sagax sagax*); jack mackerel (*Trachurus murphyi*); and mackerel (*Scomber japonicus peruanus*), particularly referring to their distributions, behaviour and availability to fisheries.

## INTRODUCCION

El régimen hídrico de la costa peruana tiene un alto nivel de producción biológica y soporta una fauna variada, distribuida en una franja relativamente angosta de 50-100 millas de ancho. La ictiofauna registrada para el mar peruano sobrepasa las 700 especies (Chirichigno, 1974), siendo cuatro las especies pelágicas que por su abundancia constituyen en la actualidad los recursos explotados de mayor importancia comercial y a las cuales nos referiremos en la presente contribución. Ellas son la anchoveta (*Engraulis ringens*), sardina (*Sardinops sagax*), jurel (*Trachurus symmetricus murphy*) y caballa (*Scomber japonicus*).

El régimen hídrico está controlado por dos fenómenos de características y efectos opuestos: el afloramiento costero y El Niño, que tienen variaciones dominantes estacionales e interanuales. Las variaciones estacionales muestran el contraste entre el verano (enero, febrero, marzo) y el invierno (julio, agosto, septiembre). El otoño (abril-julio) es algo similar al verano y la primavera (octubre-diciembre) algo similar al invierno. Las variaciones interanuales o de baja frecuencia, como El Niño o el anti-El Niño, juegan un rol importante en las fluctuaciones de la pesquería, reflejadas por las fluctuaciones de los desembarques anuales para el período 1951-82 (Fig. 1).

El afloramiento costero es el mecanismo principal en la cadena alimenticia del mar y está asociado al régimen de los vientos Alisios del Sureste (ASE), a las corrientes submarinas ricas en nutrientes inorgánicos, a la topografía de la plataforma continental y la orientación de la línea costera (O'Brien y Furlburt, 1972). El Fenómeno El Niño se presenta en períodos irregulares de tiempo (que oscilan generalmente entre 7 y 16 años), produciendo cambios bruscos y temporales en el régimen hídrico, particularmente en la capa superficial por encima de los 100 m de profundidad, con calentamientos desusuales del mar, y desplazamientos desusuales de aguas superficiales de la región ecuatorial y de la región subptropical hacia la costa peruana.

Los recursos vivos del mar están sujetos a la depredación natural y del hombre, y su distribución y abundancia dependen en buena medida de las condiciones físicas y químicas del medio marino, siendo particularmente importantes en este sentido la temperatura, la salinidad y el oxígeno disuelto.

En los últimos años se han desarrollado estudios multidisciplinarios con participación internacional frente al Perú, tales como el Joint II del CUEA y la Investigación Cooperativa de la Anchoveta y su Ecosistema (ICANE), los que han permitido importantes avances, pudiendo citarse los trabajos de Brink et al. (1981), de Codispoti y Packard (1980).

En el presente trabajo se da énfasis a los cambios estacionales e interanuales en el período 1970-83 respecto a los patrones generales de distribución de los principales parámetros físicos del mar y de los principales recursos pelágicos tales como la anchoveta, la sardina, el jurel y la caballa, con una breve mención a otros recursos ligados al ecosistema costero. Se discuten los efectos del Fenómeno El Niño en los recursos pesqueros, particularmente del evento 1982-83.

## LOS DATOS Y SU TRATAMIENTO

Los datos básicos referentes al ambiente son temperatura (T), salinidad (S), oxígeno disuelto ($O_2$), corrientes marinas (CM) y vientos (W). Los datos de T ($^{o}C$), y S ($^{o}/oo$) se presentan en la forma de mapas de superficie, secciones verticales, perfiles verticales y diagramas T-S. Los datos de $O_2$(ml/L) se presentan en perfiles verticales de verano e invierno de cuatro áreas seleccionadas (Chimbote, Callao, San Juan e Ilo), para destacar la capa mínima de oxígeno en la parte de mayor impacto de la costa peruana. Las corrientes se presentan en mapas esquemáticos, en mapas de trayectoria de boyas oceanográficas a la deriva, en mapas seleccionados de topografía (m) de la isoterma de 15$^{o}$C. La Fig.2 muestra las áreas seleccionadas y la cobertura de datos hidrográficos.

Para determinar la distribución y composición por especies de los principales recursos pelágicos, se han examinado las capturas de 3213 calas efectuadas durante 27 prospecciones Eurekas y 11 cruceros, entre septiembre 1972 y marzo 1983. Todas las calas se han efectuado con redes pelágicas y cubren una banda de hasta 80-100 millas mar afuera.

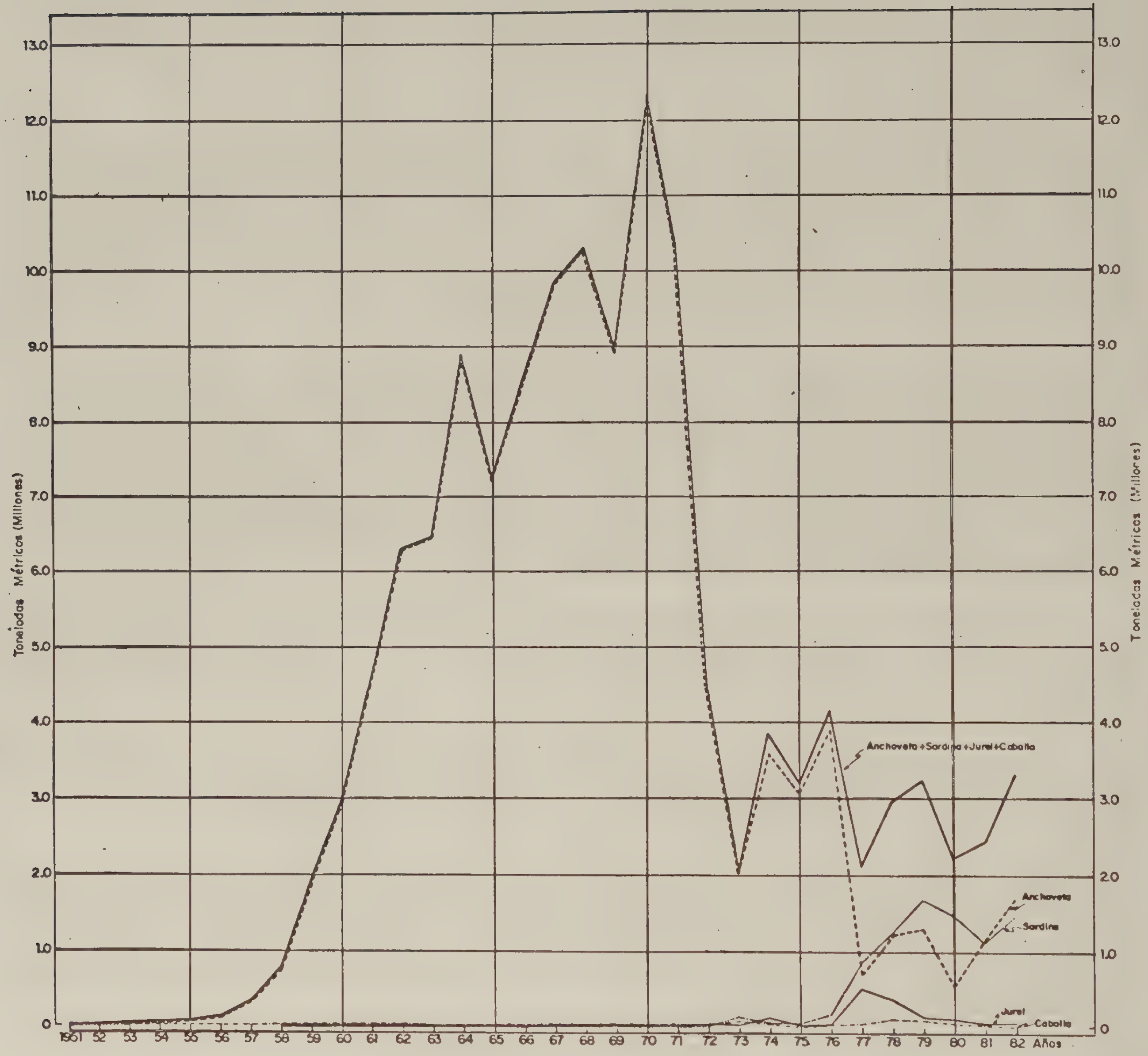
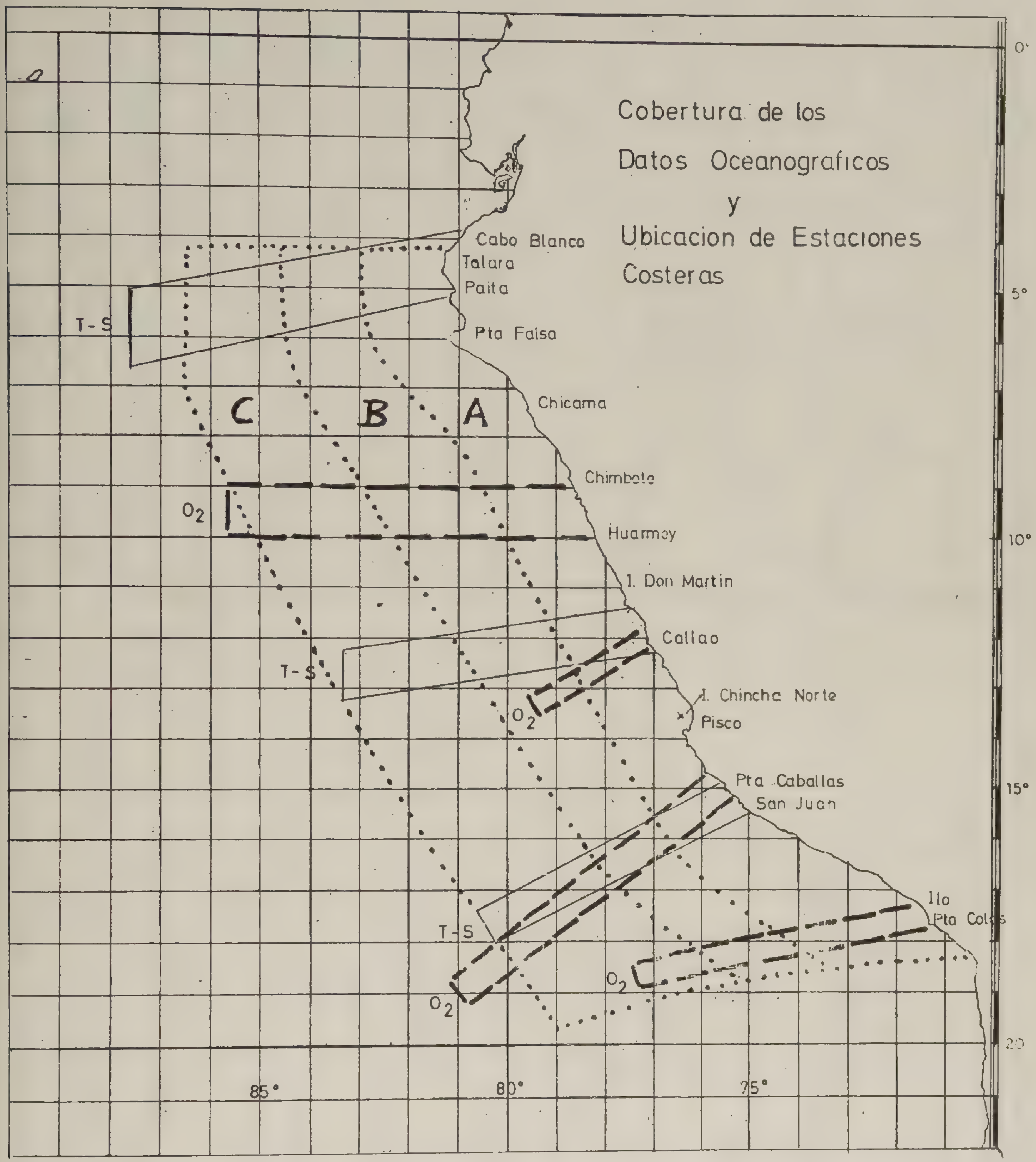


Fig. 1. Desembarques anuales de Anchoveta, Sardina, Jurel y Caballa en la costa peruana durante 1951-82

Annual landings of Anchoveta, Sardina, Jurel and Caballa off the Peruvian coast during 1951-82


Cobertura de los
Datos Oceanograficos
y
Ubicacion de Estaciones
Costeras
Cabo Blanco
Talara
Paita
Pta Falsa
Chicama
Chimbote
Huarmey
I. Don Martin
Callao
I. Chincha Norte
Pisco
Pta Caballas
San Juan
Ilo
Pta Coles
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T-S
T-S
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$O_2$
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Fig. 2.- Cobertura de los datos oceanográficos y ubicación de estaciones costeras.

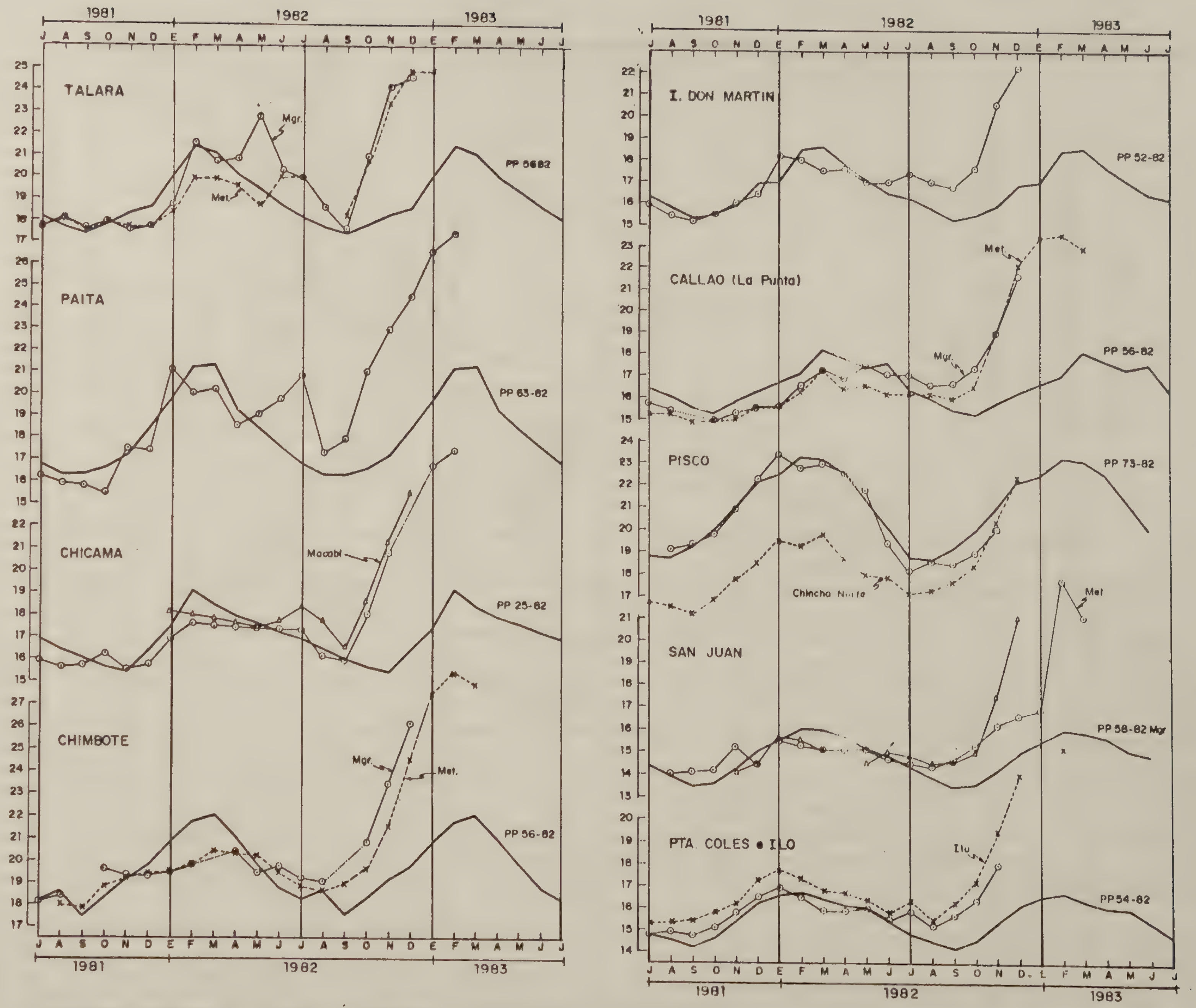


Fig. 3

Variaciones mensuales de la TSM (°C) de estaciones a lo largo de la costa peruana en el período Julio 1981 - Marzo 1983. (PP = Promedio Patrón)

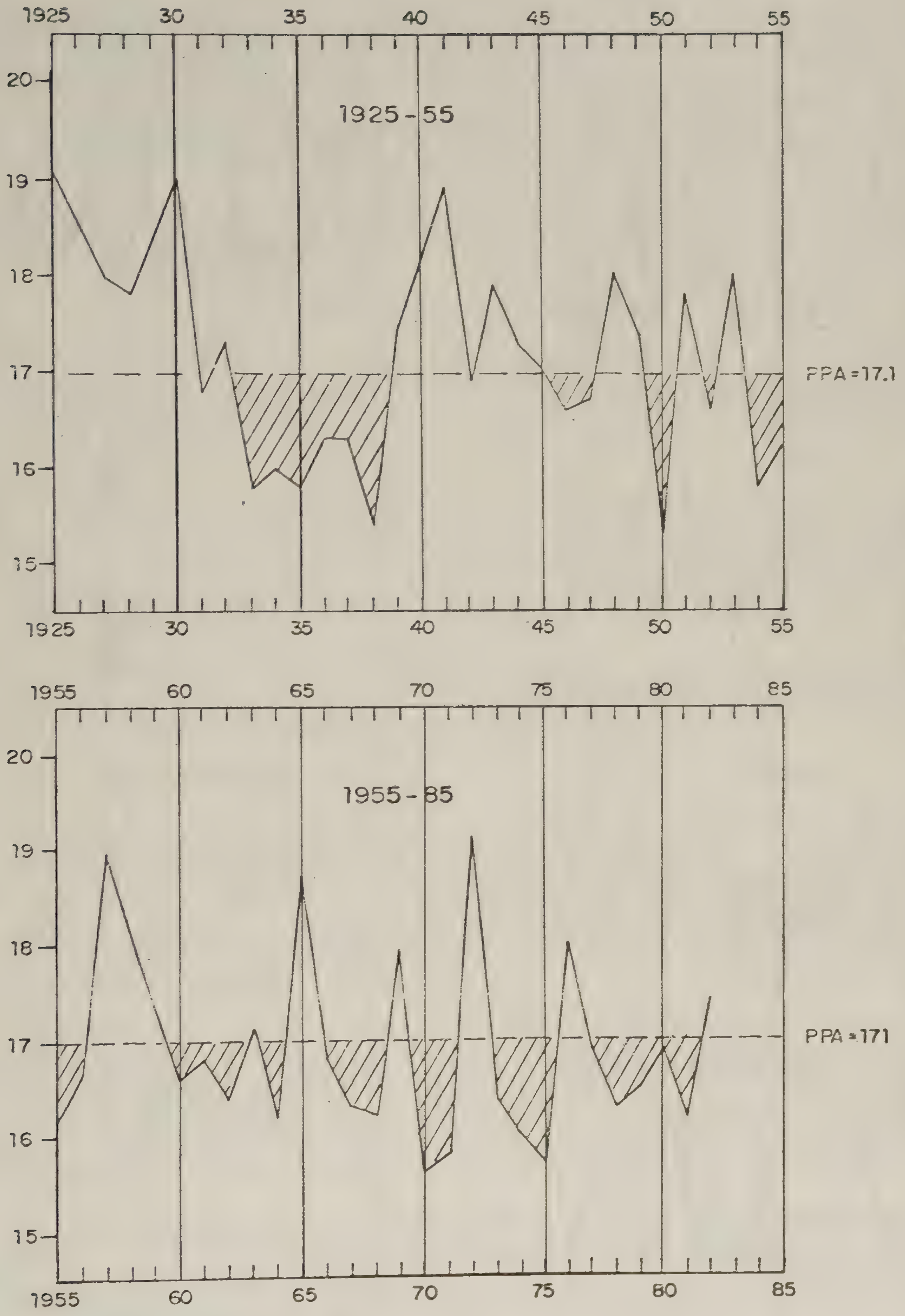


Fig. Promedios anuales de la T.S.M. de Pto. Chicama.

Fig. 4 (a)

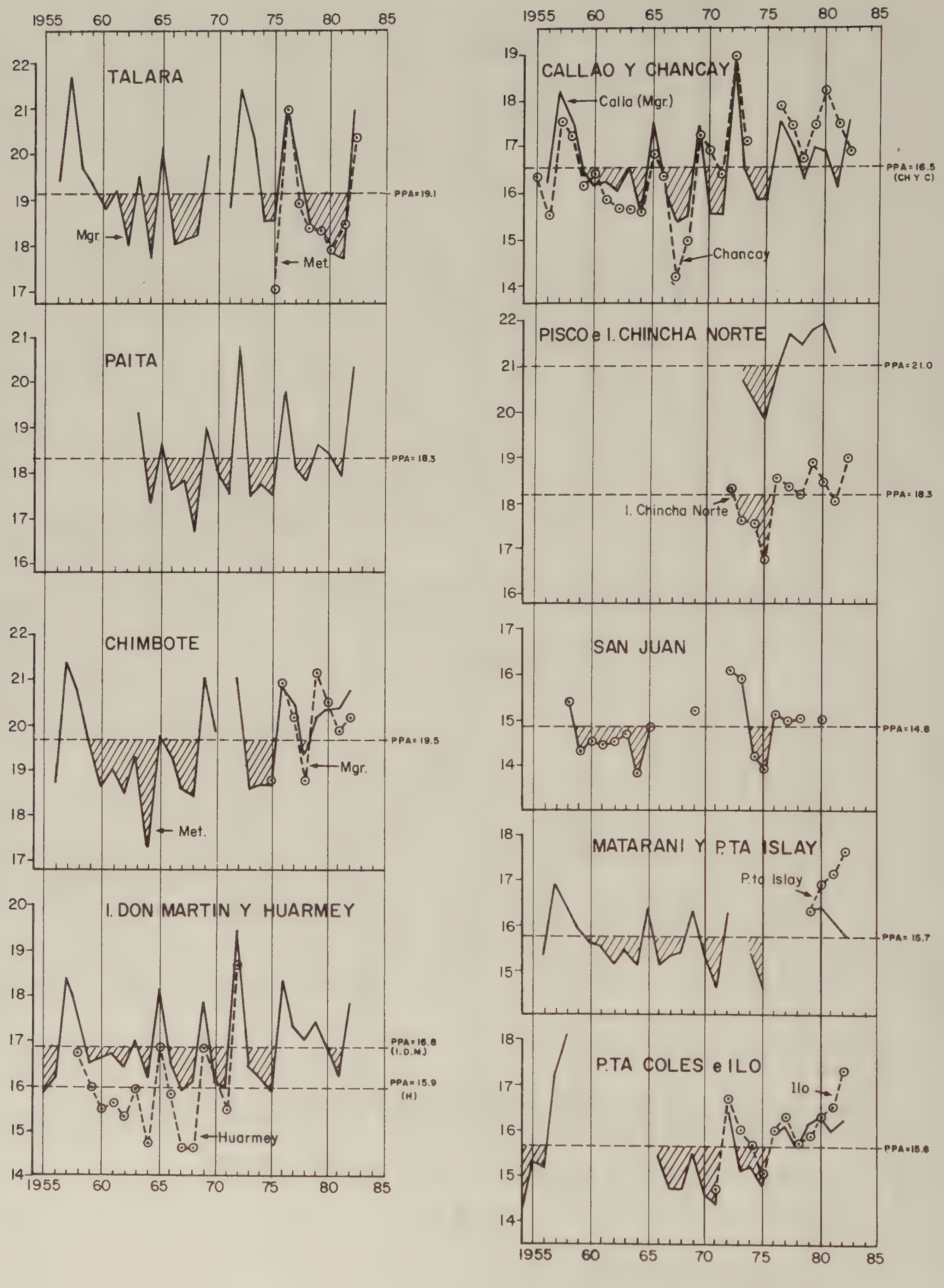


Fig. 4 (b) Variaciones de los promedios anuales de TSM ($^{0}$C) en las estaciones a lo largo de la costa peruana.

Para determinar la extensión del área de distribución, así como el grado de concentración de cardúmenes de anchoveta, se ha empleado información de detección acústica y abundancia relativa proveniente de las operaciones Eureka.

Las estadísticas de desembarque provienen del Ministerio de Pesquería, de las publicaciones de IMARPE y de los archivos de los respectivos departamentos de investigación y Laboratorios Costeros de IMARPE, así como de los Anuarios Estadísticos de FAO.

Los estimados de biomasas han sido obtenidos de publicaciones del IMARPE o de informes no publicados sobre la evaluación de los recursos pesqueros elaborados por el IMARPE para el Ministerio de Pesquería.

## EL REGIMEN HIDRICO Y SUS VARIACIONES

Las condiciones oceanográficas en la capa por encima de los 1000 m de profundidad están condicionadas por la interacción de aguas procedentes de la región ecuatorial, la región subtropical y la región subantártica, dentro de un sistema de corrientes superficiales y submarinas y el afloramiento costero asociado al régimen de los vientos alisios del suroeste.

Como característica propia de la circulación en el margen oriental del Pacífico (Stommel, 1948), las corrientes frente al Perú son lentas y de poco transporte, lo que favorece los cambios temporales. En determinados períodos los cambios son espectaculares, como en los casos del evento El Niño, de enormes efectos socio-económicos. De particular interés es el evento El Niño 1982-83 que tiene características singulares y que ha conmovido la economía del país y la colaboración internacional.

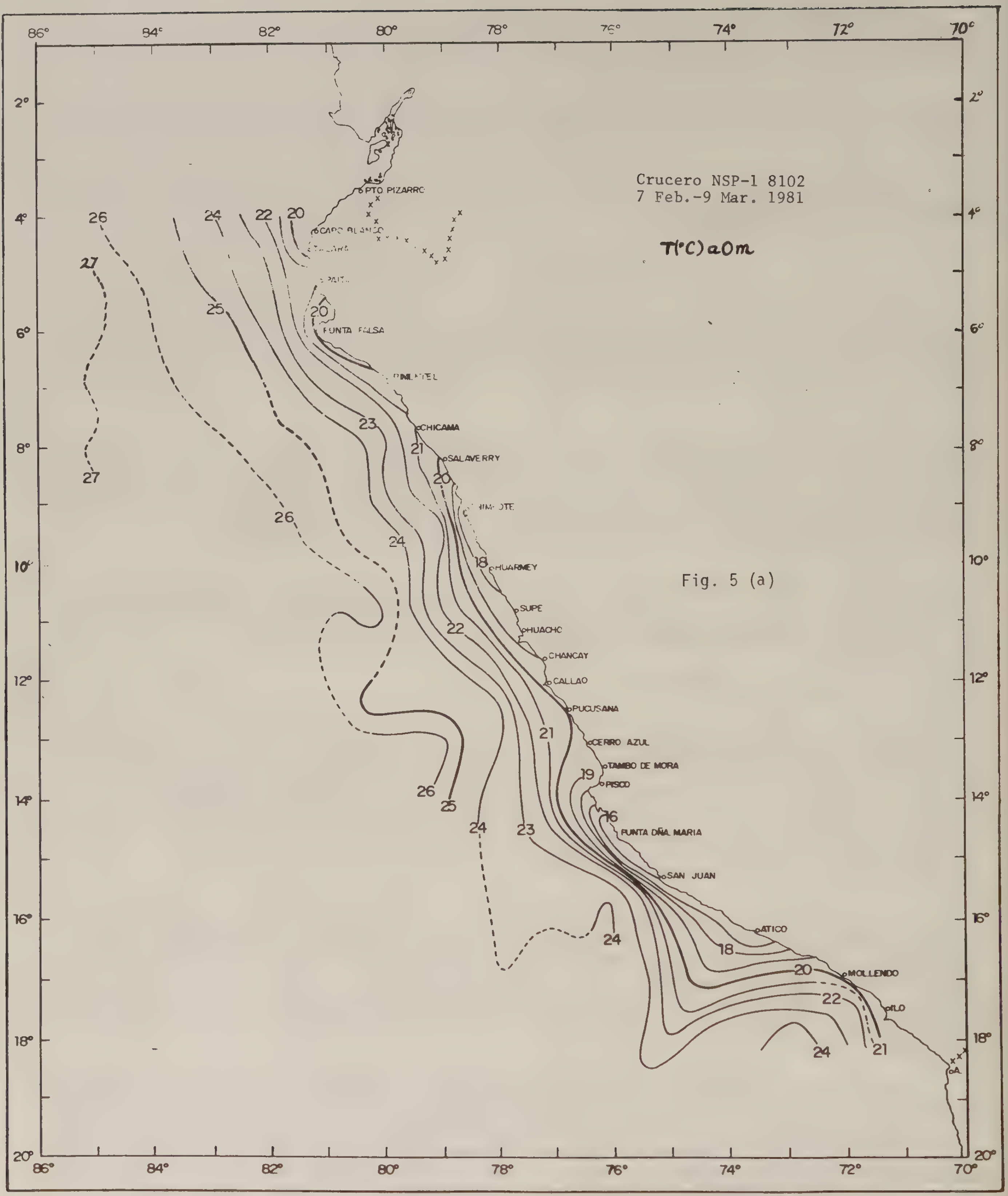
Las variaciones se presentan en diferentes escalas de tiempo y espacio; pero en este trabajo sólo se discuten las variaciones estacionales o interanuales que son dominantes en el área de estudio y de gran incidencia en la distribución, abundancia y fluctuaciones de los recursos pesqueros, particularmente de los recursos pelágicos.

### Temperatura Superficial del Mar (TSM)

a) Características normales. En la Fig. 3 se muestran los patrones de distribución de 9 estaciones fijas a lo largo de la costa, y los cambios ocurridos en dichos lugares en el período de julio 1981 a abril 1983. Se aprecia que normalmente las temperaturas más elevadas se presentan en febrero (Talara, Chicama, Pisco, San Juan y Pta. Coles) o marzo (Paita, Chimbote, Don Martín y Callao), y las más bajas principalmente en septiembre y en algunos casos en agosto (Pisco), octubre (Callao) y noviembre (Chicama), con un rango mayor en Talara (4.1°C), Paita (5.0°C) y Chimbote (4.2°C) y menor en San Juan (2.5°C) y Pta. Coles (2.5°C).

El enfriamiento dura de 6 a 9 meses, a un ritmo variado. Es más rápido en Talara, Paita, Chimbote y Pisco. El calentamiento dura de 3 a 6 meses y es generalmente más rápido que el enfriamiento, especialmente en Chicama y Chimbote. El calentamiento se produce de manera ininterrumpida; pero el enfriamiento sufre interrupciones en algunos lugares con los picos de calentamiento secundario que se presentan en Chimbote (agosto), Callao (junio) y Pta. Coles (julio), los que son denominados (Mugica, 1972) veranillos de invierno.

En la Fig. 4 se presentan las variaciones de los promedios anuales de la TSM, correspondientes a las mismas estaciones costeras mencionadas en el párrafo anterior. El promedio patrón anual (PPA) da una idea de las desviaciones respecto al patrón. Tomando como estaciones básicas de referencia a Talara, Chicama, Chimbote, I. Don Martín y Callao (ver ubicación en Fig. 2), podemos ver que los picos con desviaciones positivas de 1°C o más en por lo menos 3 de ellas corresponden a los años 1925, 1930, 1941, 1948, 1953, 1957, 1965, 1972, 1976 y 1982, catalogados muchos de ellos como de eventos de El Niño de intensidad fuerte y moderada (Quinn et al., 1982; Zuta et al., 1976; etc.). Los picos de desviaciones negativas con valores absolutos de 1°C o más, en por lo menos en 3 estaciones, corresponden a los años 1933, 1938, 1950, 1964, 1968, 1971 y 1975. Los años de condiciones más próximas a lo normal corresponden a los períodos 1931-32, 1945-46, 1960-61 y 1978. Hay pues, una secuencia de períodos normales (promedio o patrón), fríos y cálidos que ocurren a intervalos irregulares de tiempo y con intensidades diferentes.



Crucero NSP-1 8102
7 Feb.-9 Mar. 1981

T(°C) a 0m

Fig. 5 (a)

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PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
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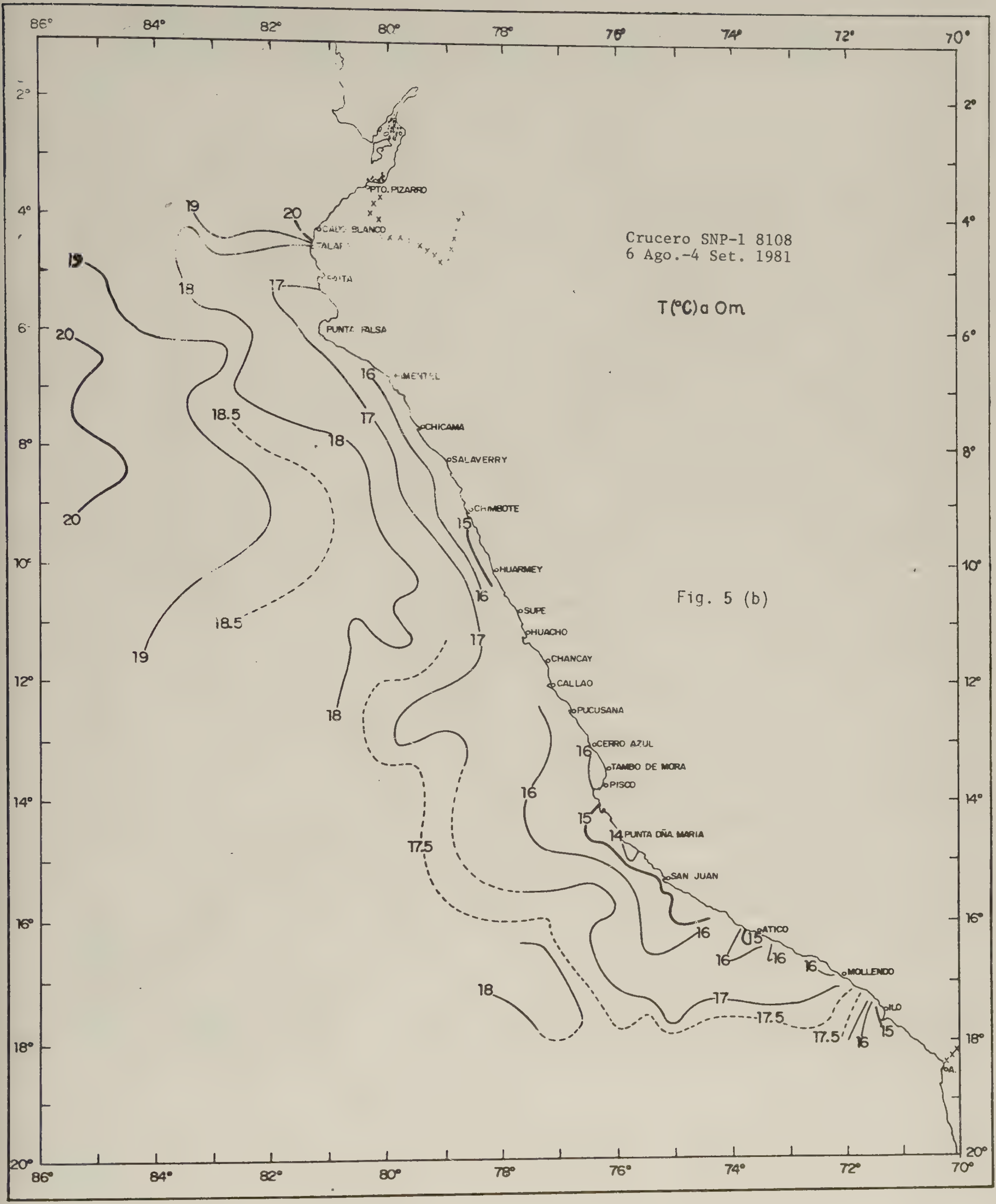
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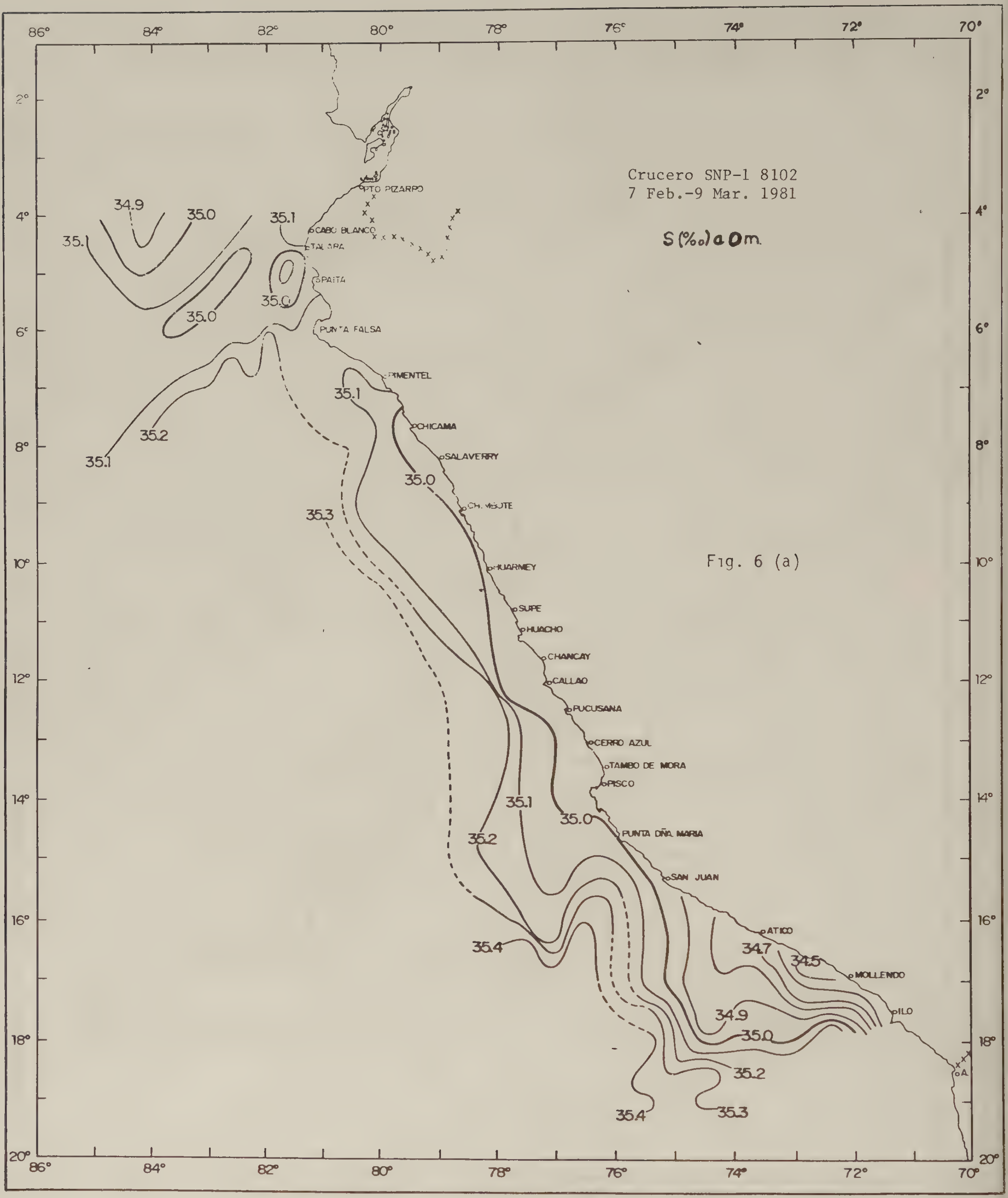
Crucero SNP-1 8108
6 Ago.-4 Set. 1981

T(°C) a Om

Fig. 5 (b)


Crucero SNP-1 8102
7 Feb.-9 Mar. 1981

S(‰) a 0m.

Fig. 6 (a)

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ATICO
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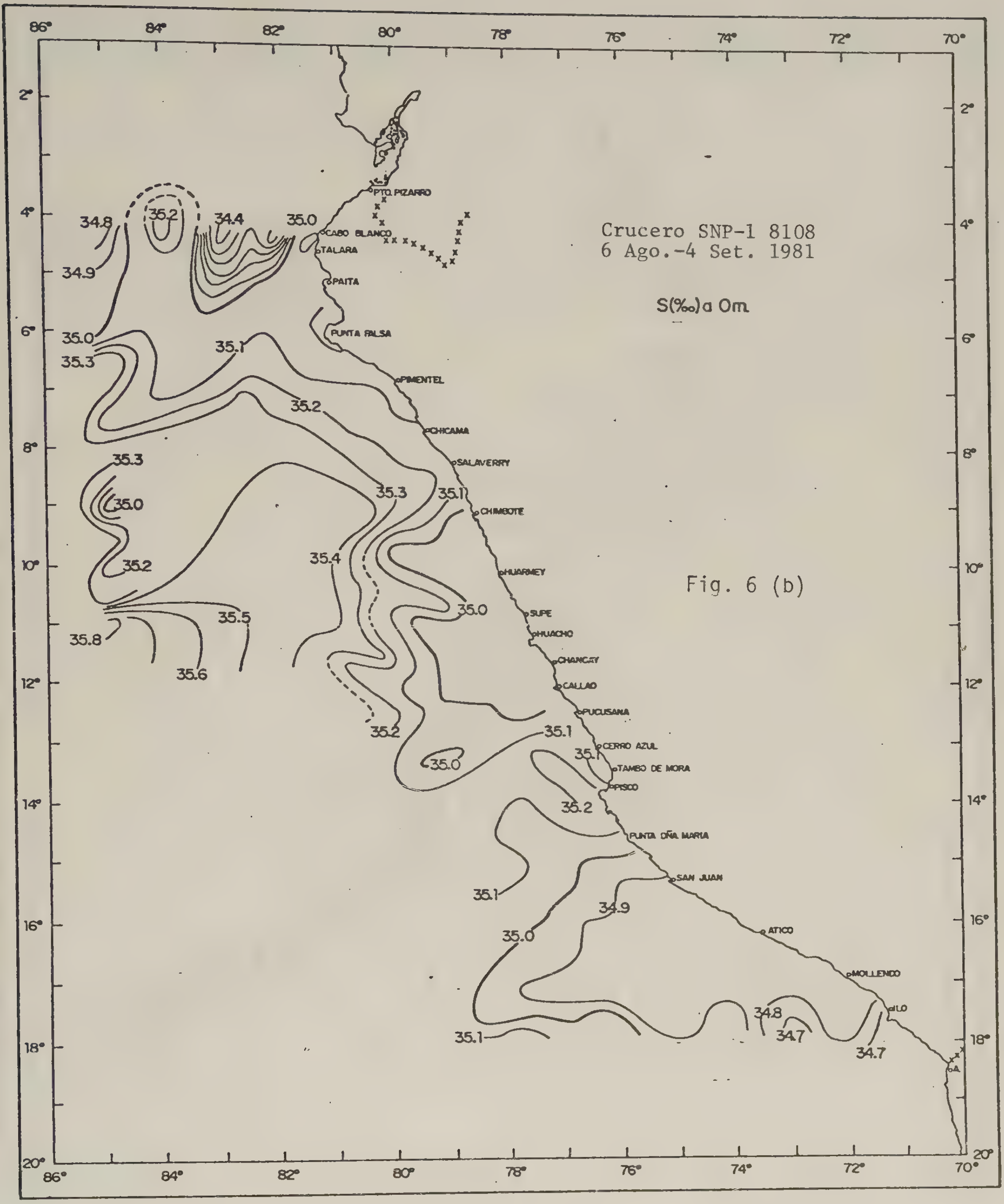
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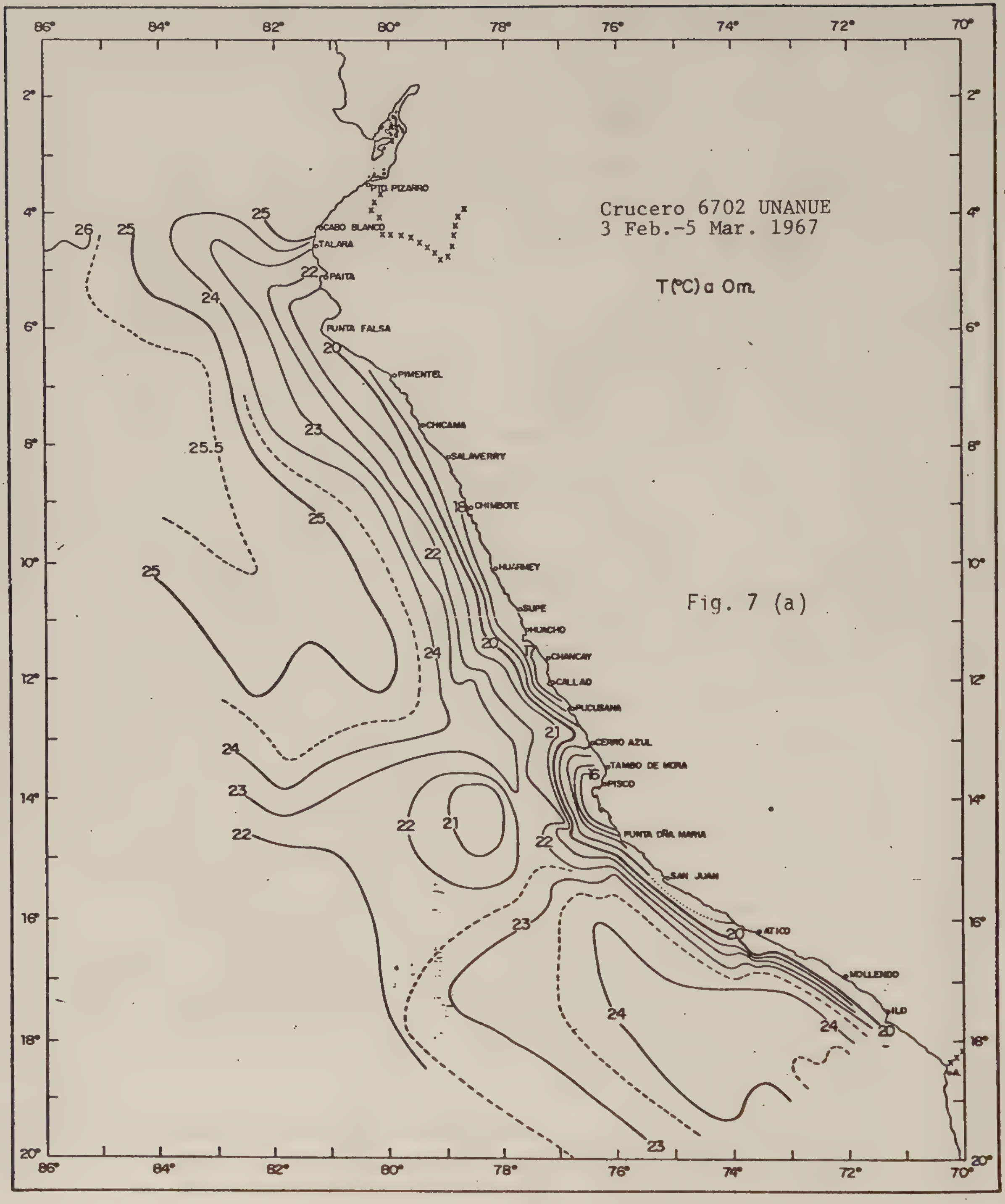
Crucero SNP-1 8108
6 Ago.-4 Set. 1981

S(‰) a 0m

Fig. 6 (b)



Crucero 6702 UNANUE
3 Feb.-5 Mar. 1967

T(°C) a 0m

Fig. 7 (a)

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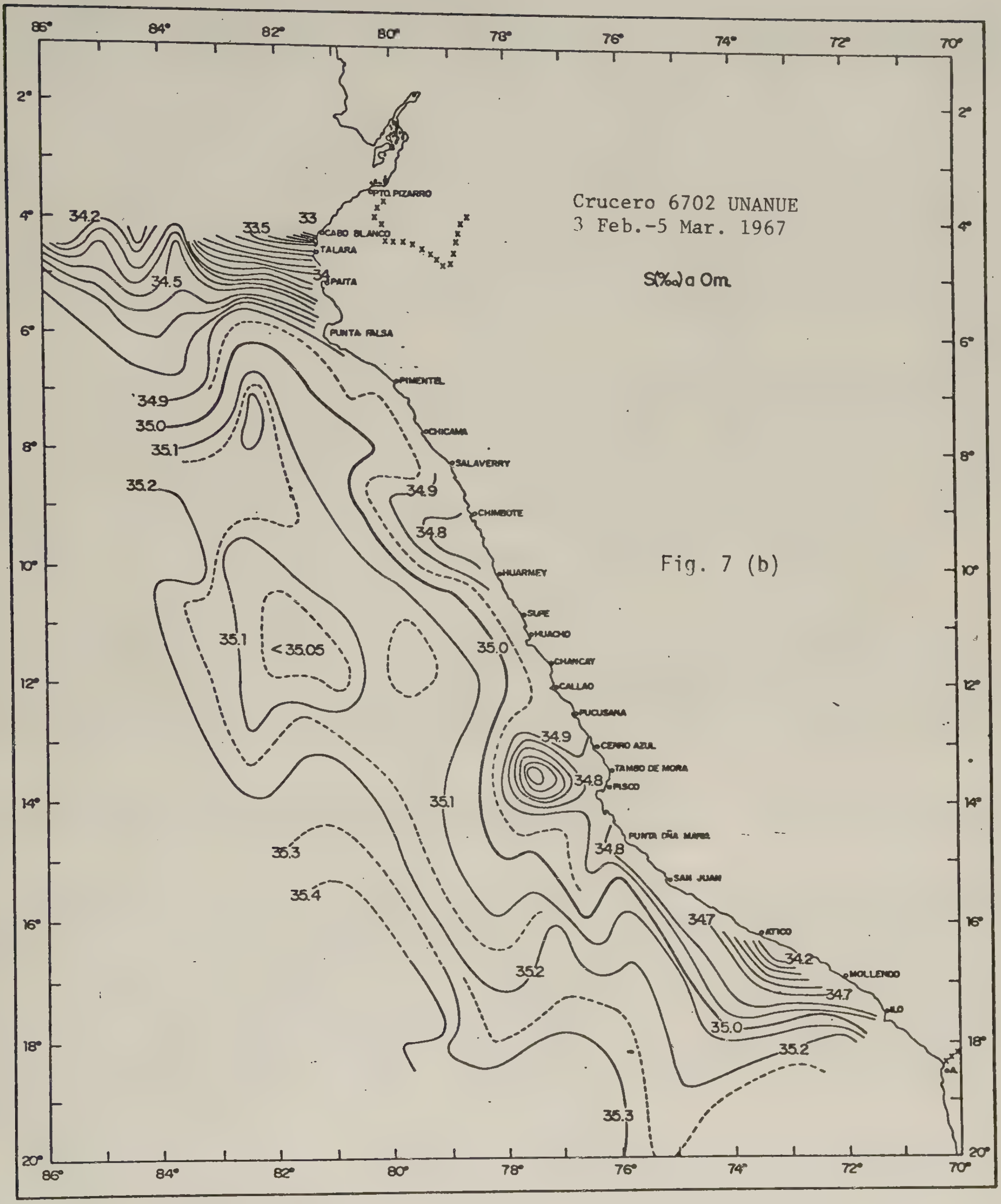

Crucero 6702 UNANUE
3 Feb.-5 Mar. 1967

S(‰) a 0m.

Fig. 7 (b)

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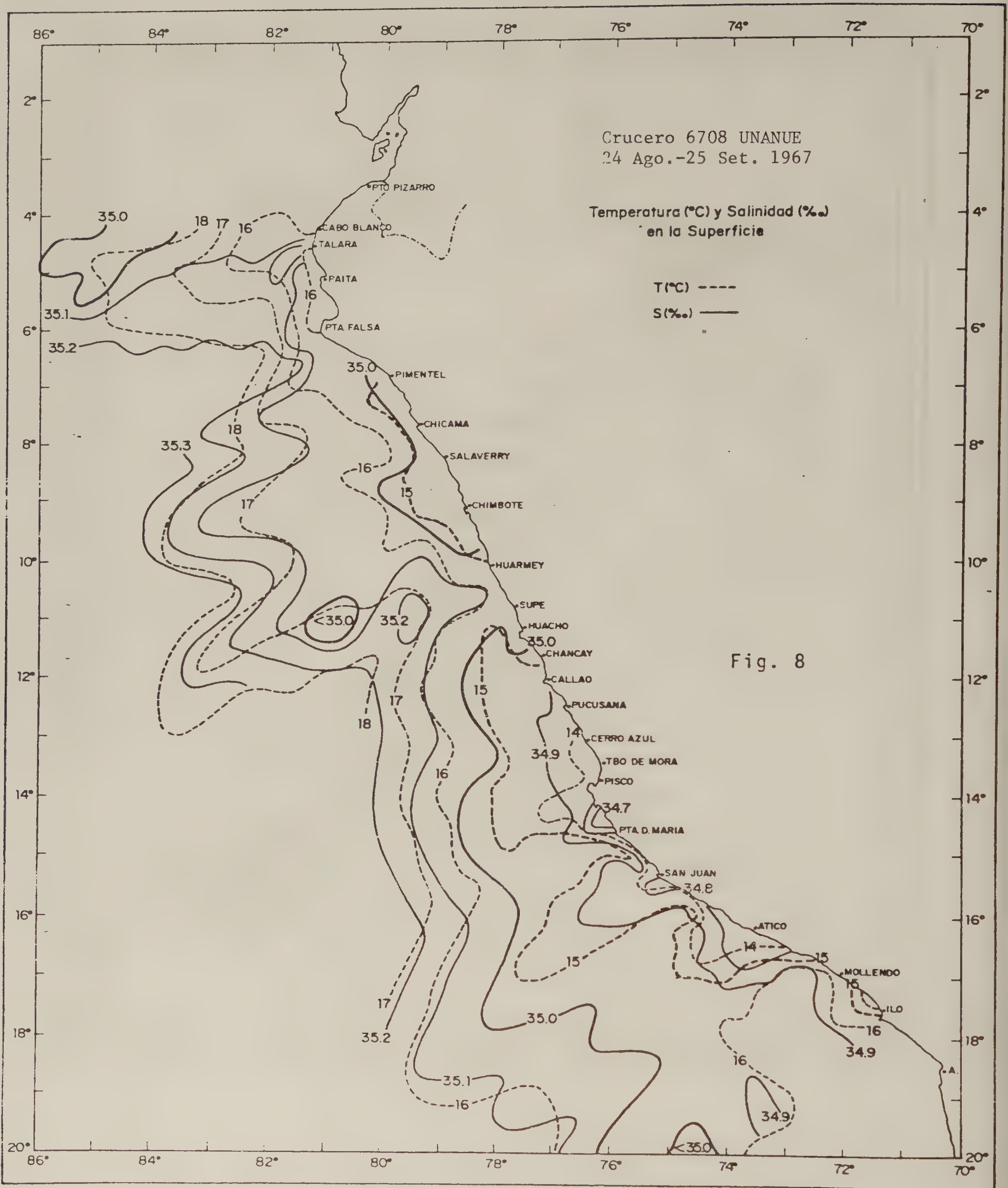
Crucero 6708 UNANUE
24 Ago.-25 Set. 1967
Temperatura (°C) y Salinidad (‰) en la Superficie
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<35.0

Fig. 8

Los gráficos de la Fig. 5 (a, b) y 6 (a, b) correspondientes a dos cruceros oceanográficos de 1981 (Rivera, 1982; Flores, 1982), se han seleccionado como respresentativos de un verano e invierno típicos o normales (hubiera sido deseable tomar 1978, pero no hay cruceros apropiados para ese año). Estos muestran los cambios extremos que se producen entre el verano e invierno.

En el verano (Fig. 5a) las isotermas de 16-24°C desarrollan una fuerte gradiente horizontal dentro de las 40-100 millas de la costa, mucho más intensa entre los 14° -17°S, en asociación con el afloramiento costero y la aproximación de aguas calientes oceánicas, particularmente frente a San Juan (15°S), donde se concentran 8 isotermas (16° -23°C) en una banda de 35 millas. Más allá de esta banda de contraste térmico, las isotermas de 24 a 27°C presentan un gradiente suave. La isoterma de 20°C se extiende a lo largo de gran parte de la costa y muy cerca a ella, con dos interrupciones, una alrededor de Paita (5°S) y otra entre Pimentel-Salaverry (7-8°S).

En el invierno (Fig. 5b) la situación es notablemente diferente, con un gradiente horizontal muy débil y sólo apreciable con las isotermas de 15-17°C dentro de las 50 millas de la costa. La isoterma de 17°C que en el verano se extiende entre Pisco-Atico (14-16°S), en el invierno se extiende entre Paita-Mollendo (5-17°S). La isoterma de 20°C que en el verano aparece muy pegada a la costa, en el invierno se hace presente más allá de las 240 millas de la costa, en el lugar que ocupaba la isoterma de 27°C en el verano. El área de afloramiento entre Pisco y Atico aparece en el verano con temperaturas de 16-17°C, y en el invierno con temperaturas de 14-16°C y en el invierno es también notable el afloramiento entre Paita-Pta. Falsa (5-6°S), con temperaturas menores de 17°C.

Las variaciones medias del verano al invierno son menores de 5°C cerca de la costa y pueden exceder de 10°C lejos de la costa (Zuta y Urquizo, 1972), este último caso en asociación con la lengua caliente que se desarrolla de octubre a abril con el eje a 150-300 millas de la costa, disminuyendo de distancia hacia el sur hasta pegarse a la costa chilena entre los 20-23°S como se puede ver en las cartas de Wyrtki (1964). De diciembre a marzo esta lengua muestra una transgresión ecuatorial al este de las Islas Galápagos, que rompe el frente ecuatorial.

b) Características de un período de frío o de anti-El Niño. Las Figs. 7, 8 y 9 muestran las condiciones de verano e invierno, respectivamente en un período frío o de anti-El Niño.

La Fig.7 a corresponde al verano de un período frío. Muestra temperaturas de 16 a 26°C dentro de las 300 millas, con un gradiente horizontal notable dentro de las 80 millas entre los 6-14°S (isotermas de 17-23°C), y dentro de las 45 millas entre 14-18°S (isotermas de 16-23°C). La lengua caliente de verano presenta su eje a 120-250 millas de la costa, con una aproximación hacia el sur y es interrumpida frente a Pisco aparentemente para el afloramiento en esta zona. Las temperaturas bajas a los 83°W frente a Talara son resultado del afloramiento costero entre Talara-Pta. Falsa. Las temperaturas más altas en la parte costera al norte de Talara están asociadas con la extensión del frente ecuatorial que se destaca claramente por la salinidad. La isoterma de 20°C se extiende alrededor de las 20 millas de la costa entre los 6-18°S.

En el invierno de 1970 (Fig. 9a), la TSM presenta valores de 13 a 17° entre los 4°30'-18°30'S y dentro de las 130 millas de la costa. Las temperaturas altas de 18 a 24°C en la parte costera al norte de Talara, están relacionadas con el frente ecuatorial que se destaca aún más con las salinidades bajas como se describe en el subtítulo que sigue. La isoterma de 15°C que se extiende entre Talara-Pta. Falsa y prácticamente en forma interrumpida entre Pimentel-Ilo, refleja el desarrollo notable del afloramiento en gran parte de la costa peruana, con los focos principales alrededor de Paita, frente a Pimentel, Chimbote, Callao, Pta. Caballas y sur de Ilo. El afloramiento frente a Pisco, evidentemente el más intenso, presenta cerca de la costa temperaturas ligeramente menores de 13°C. La isoterma de 15°C al norte de los 6°S revela también un afloramiento intenso en esta parte.

c) Características de un período cálido o de El Niño. Las Figs. 10a y 10b muestran las características del verano e invierno en períodos de evento El Niño. En el verano (Fig. 10a) la superficie del mar presenta temperaturas de 21-29°C al norte de los 12°S y dentro de las 200 millas, con la isoterma de 25°C muy pegada a la costa hasta los 9°S (Chimbote). En la parte sur la franja de 120 millas presenta temperaturas de 15-26°C, con la mínima alrededor de Pta. Caballas. El gradiente térmico más intenso aparece entre Pta. Caballas

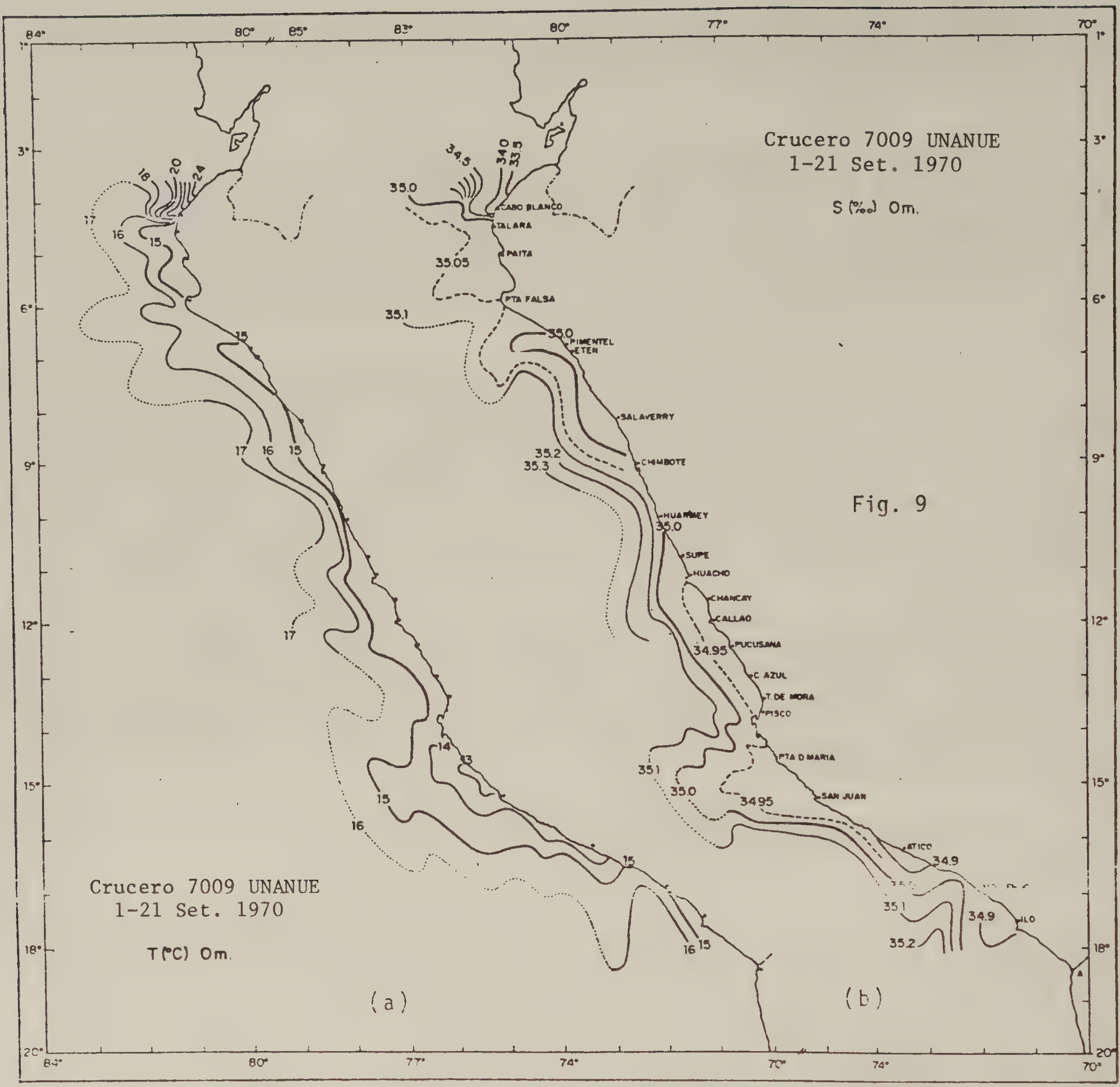

Crucero 7009 UNANUE
1-21 Set. 1970
T(°C) Om.
(a)
Crucero 7009 UNANUE
1-21 Set. 1970
S (‰) Om.
(b)
CABO BLANCO
TALARA
PAITA
PTA FALSA
PIMENTEL
ETEN
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
C AZUL
T. DE MORA
PISCO
PTA D MARIA
SAN JUAN
ATICO
ILO
84°
80°
77°
74°
70°
1°
3°
6°
9°
12°
15°
18°
20°

Fig. 9

e Ilo, como efecto del afloramiento prevaleciente y la aproximación de la lengua caliente mencionada anteriormente y que en este caso es de mayor intensidad y mayores temperaturas. La isoterma de 20°C sólo aparece entre Cerro Azul (13°S) y Mollendo (17°S) y al sur de Ilo.

En el invierno (Fig. 10b) los datos muestran un ligero enfriamiento de agosto a septiembre con las aguas más calientes al norte de los 12°S (Callao) con temperaturas de 17-21°C dentro de las 150 millas. Al sur de dicha latitud las temperaturas fueron de 15.0 a 17.5°C y la isoterma de 16°C se extendió en un área reducida. Los núcleos principales de afloramiento se presentaron frente a Salaverry (8°S), Supe (11°S), San Juan (15°S) y Atico (16°S). Las aguas oceánicas muestran temperaturas apreciablemente más altas de lo que ocurre en un año normal o aproximadamente normal como 1981 (Fig. 5b).

## Salinidad Superficial del Mar (SSM)

a) Características normales. Las Figs. 6a y 6b muestran las características de salinidad de verano e invierno del año 1981 catalogado como un año de tendencias predominantemente normales. En el verano (Fig. 6a) las salinidades mayores de 35.1°/oo, correspondientes a las aguas subtropicales superficiales (ASS), predominan al sur de los 6°S y más allá de las 60 millas. Las aguas con salinidades menores de 35.0°/oo resaltan dentro de las 60 millas y se extienden a mayores distancias de la costa al norte de los 6°S, como propagación de las aguas de baja salinidad de la región ecuatorial. La franja costera entre los 6-14°S resalta por ser bastante homogénea, en tanto que la parte al sur de los 16°S es notable por el gradiente intenso de salinidad, al parecer resultante del encuentro de las aguas de descarga de los ríos en la época de verano y la aproximación de las aguas subtropicales superficiales (ASS).

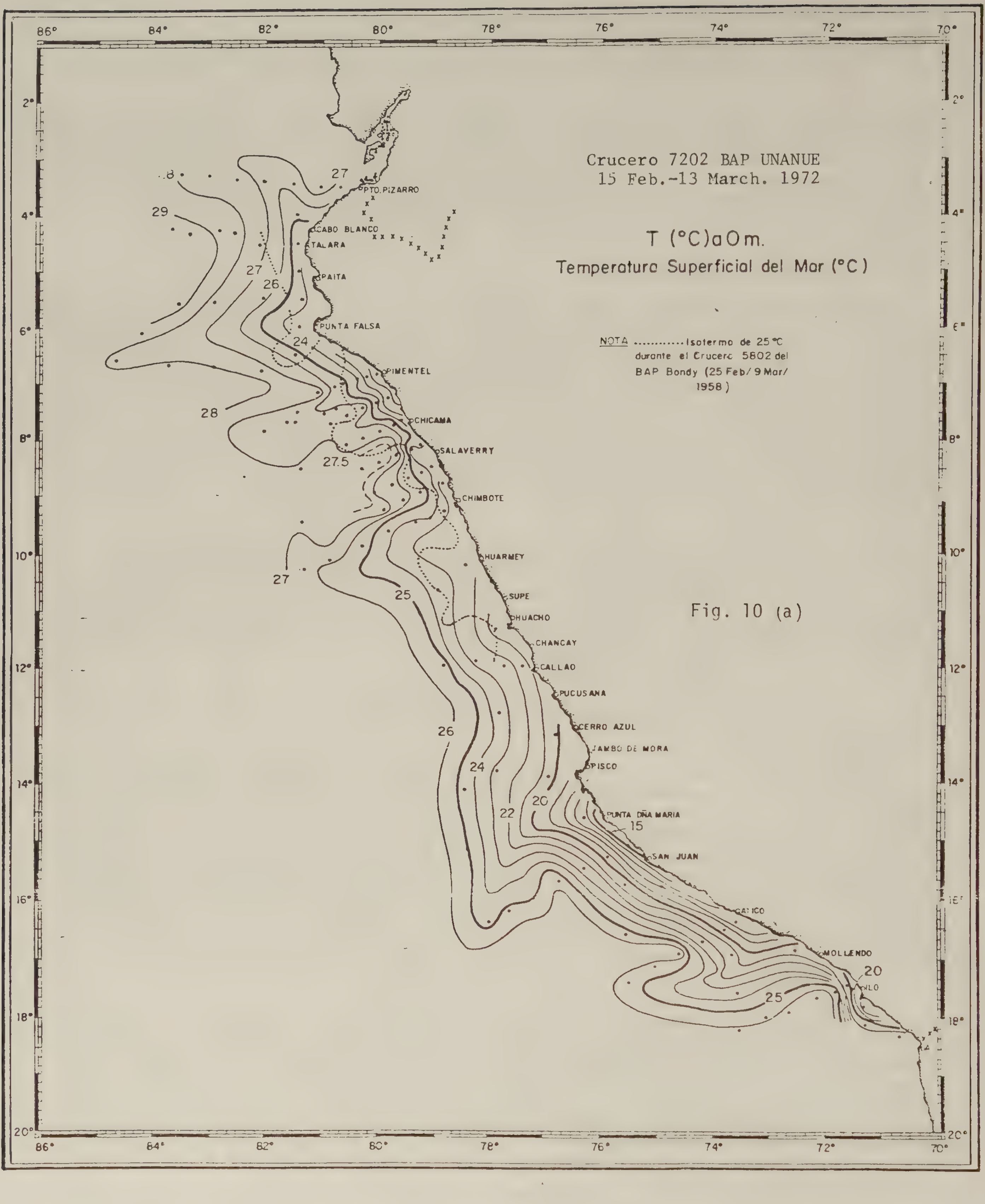
La situación cambia bastante en toda la costa en invierno (Fig. 6b). Dentro de las 120-200 millas las aguas son notablemente homosalinas al sur de los 9°S (Chimbote). Las ASS se alejan notablemente de la costa al sur de los 12°S, y más al norte aumentan sus salinidades hasta los 7°S y se pegan a la costa a los 8°S (Salaverry), asociadas fundamentalmente con temperaturas de 18-20°C. Al norte de los 6°S, se hacen presente en forma apreciable las aguas ecuatoriales superficiales (AES), de baja salinidad, con salinidades hasta de 34.4°/oo frente a Cabo Blanco.

b) Características de un período frío o de anti-El Niño. Las condiciones de un año frío se muestran en las Figs. 7b y 9b.

En el verano de 1967 (Fig. 7b) las aguas de baja salinidad de la región ecuatorial ocuparon toda la zona hasta 6°S y 86°W y se proyectaron en parte hasta los 7°S por el lado oeste de los 83°W. Las isohalinas de 32.7 a 34.8°/oo mostraron un gradiente intenso al norte de los 6°S, especialmente al este de los 83°W. Entre los 6-15°S, las isohalinas muestran un gradiente suave, especialmente dentro de las 100 millas. Al sur de los 15°S, el gradiente se vuelve apreciable dentro de las 120 millas, con las aguas de baja salinidad hasta de 34.6°/oo en el lado costero y las aguas de alta salinidad en el lado oceánico. Las aguas subtropicales superficiales se presentan con valores de 35.1-35.4°/oo, generalmente más allá de las 100 millas de la costa y al sur de los 6°S, y sólo frente a Ilo se aproxima a 30 millas de la costa. Las salinidades bajas cerca de la costa frente a Huarmey y Atico podrían tener relación con la descarga de ríos de la temporada.

En el invierno de períodos fríos como 1967 y 1970 (Figs. 8, 9b), las aguas subtropicales superficiales (salinidades mayores de 35.1°/oo) se extienden hacia el norte hasta cerca de los 4°S, pegándose a la costa frente a Talara y Huarmey, principalmente. Las aguas de baja salinidad de la región ecuatorial suelen presentarse por el lado costero al norte de Talara, en el caso de 1970 con valores de 33.3 a 34.8°/oo. Las aguas costeras al sur de los 6°S muestran valores menores de 35.0°/oo entre Pimentel-Huarmey y entre Supe-Ilo, aunque en 1967 la isohalina de 35.0°/oo se proyecta muy lejos de la costa hasta por lo menos 20°S, frente a Chile; en tanto que en 1970 las ASS estuvieron mucho más pegadas a la costa desde los 9°S hacia el sur.

Tanto los períodos normales, fríos y cálidos presentan variaciones de una época a otra, y el área al sur de los 12°S suele presentar un aspecto diferente al área del lado norte, como en el invierno de 1968 (Cr. 6808 Unanue) que fue caliente en la parte norte y frío en la parte sur.



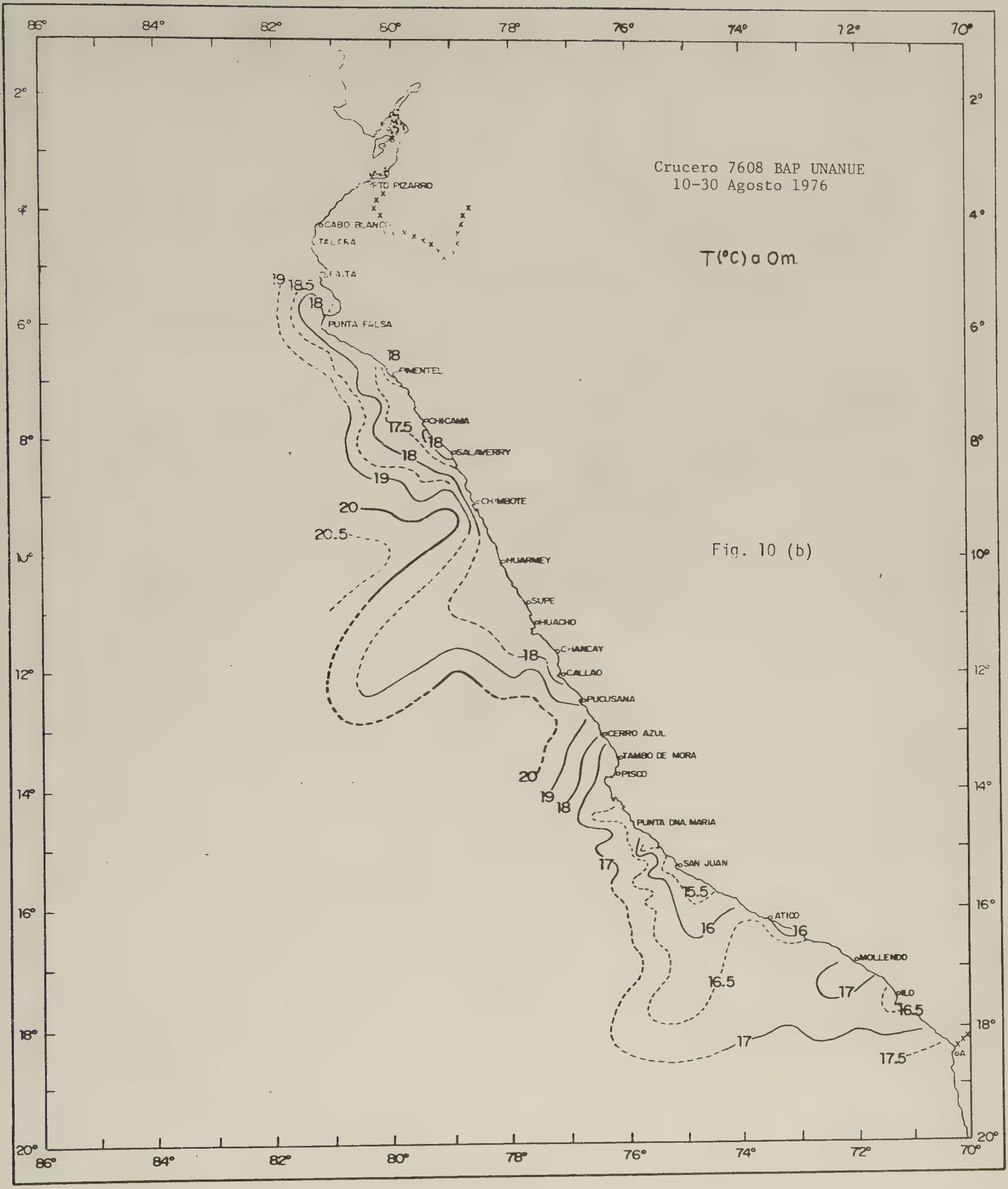
Crucero 7202 BAP UNANUE
15 Feb.-13 March. 1972

T (°C) a 0 m.
Temperatura Superficial del Mar (°C)

NOTA ............ Isotermo de 25 °C durante el Crucero 5802 del BAP Bondy (25 Feb/ 9 Mar/ 1958)

Fig. 10 (a)

86°
84°
82°
80°
78°
76°
74°
72°
70°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
PTO. PIZARRO
CABO BLANCO
TALARA
PAITA
PUNTA FALSA
PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
SAN JUAN
MOLLENDO
ILO
29
28
27
27.5
26
25
24
22
20
15



Crucero 7608 BAP UNANUE
10-30 Agosto 1976

T(°C) a 0m.

Fig. 10 (b)

86°
84°
82°
80°
78°
76°
74°
72°
70°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
PTO PIZARRO
CABO BLANCO
TALARA
PAITA
PUNTA FALSA
PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DNA MARIA
SAN JUAN
ATICO
MOLLENDO
ILO
A
19
18.5
18
18
17.5
18
18
19
20
20.5
18
20
19
18
17
15.5
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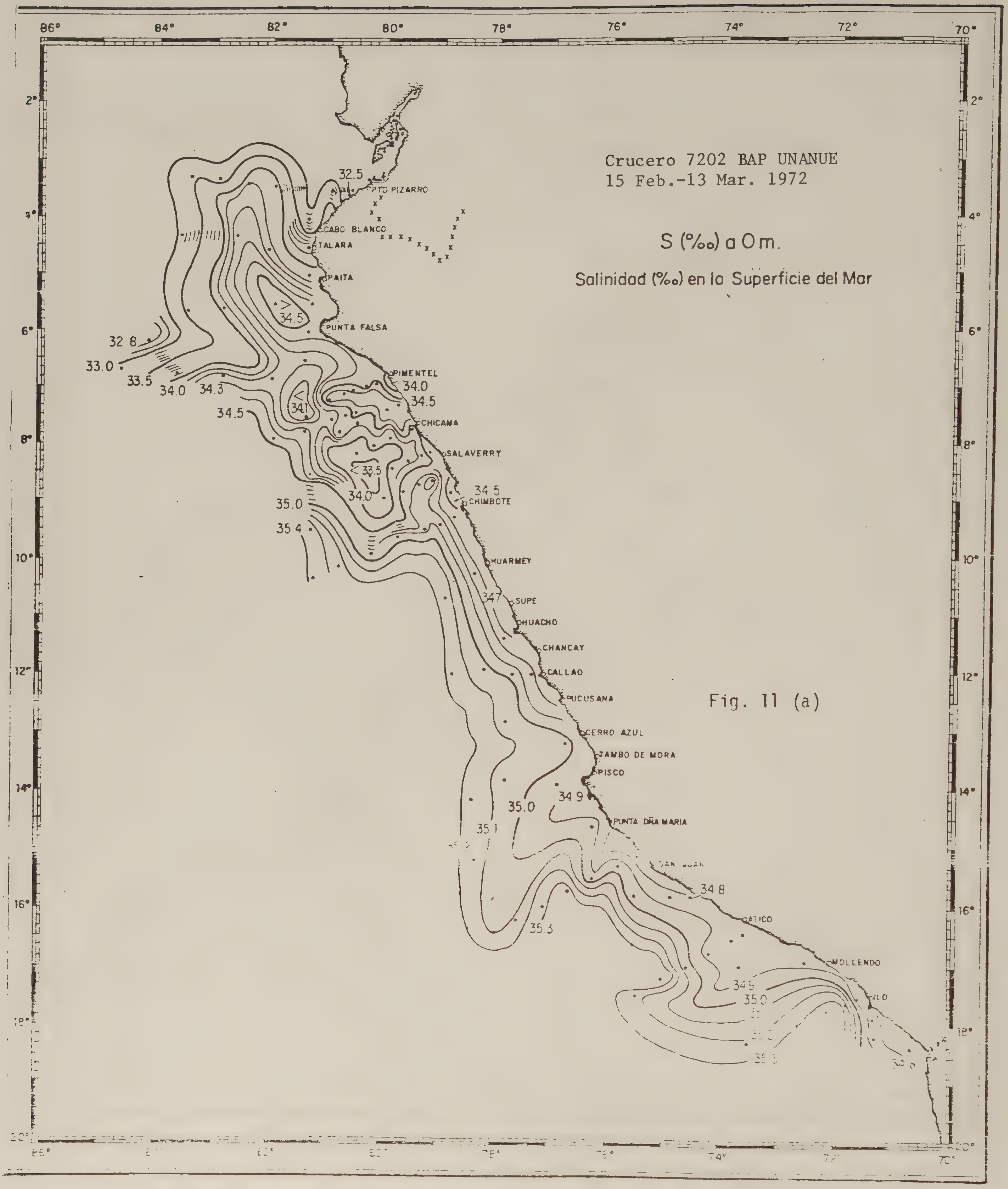
16
16.5
17
16.5
17
17.5



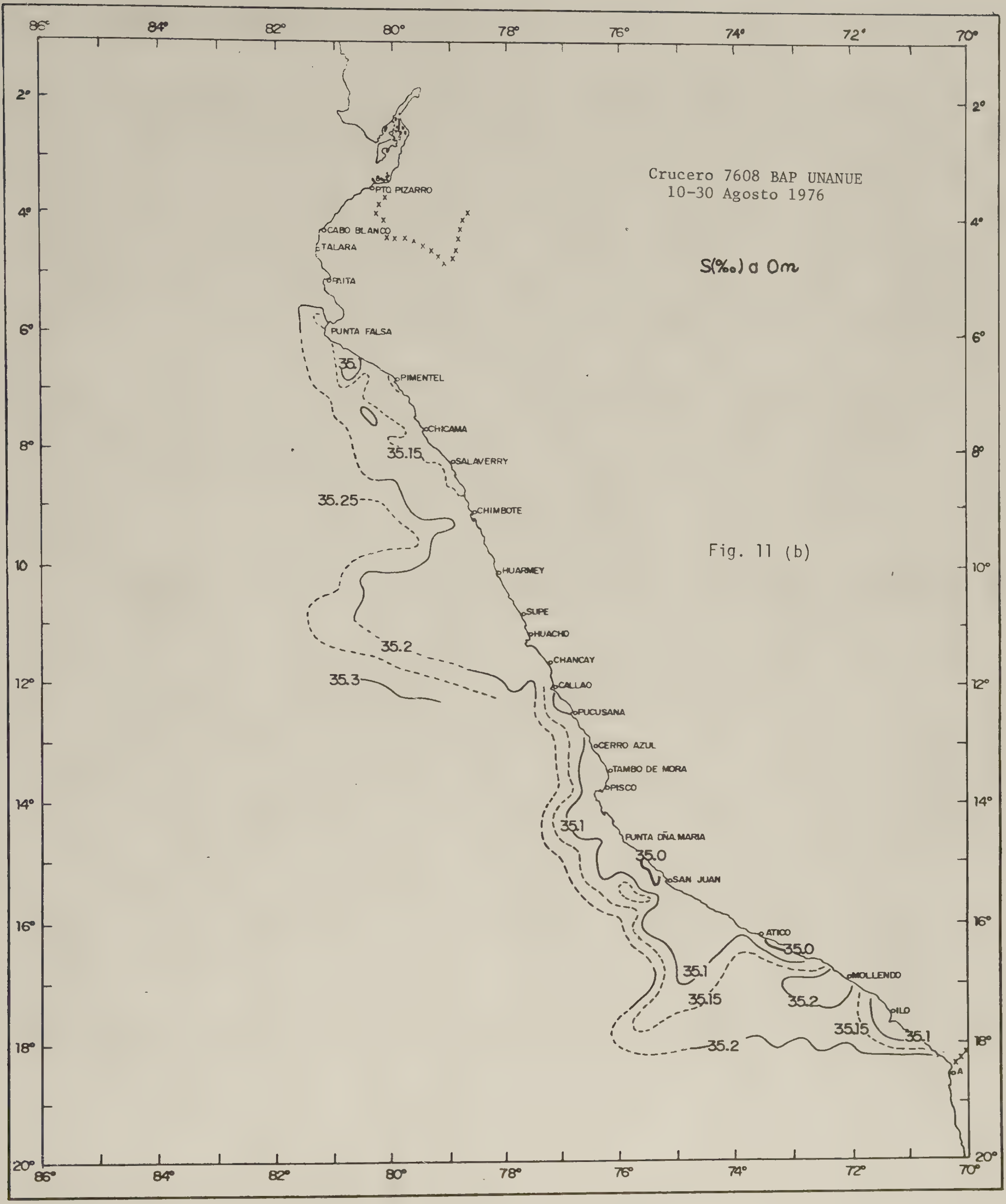
Crucero 7202 BAP UNANUE
15 Feb.-13 Mar. 1972

S (‰) a 0 m.

Salinidad (‰) en la Superficie del Mar

Fig. 11 (a)

86°
84°
82°
80°
78°
76°
74°
72°
70°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
PTO PIZARRO
CABO BLANCO
TALARA
PAITA
PUNTA FALSA
PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
SAN JUAN
ATICO
MOLLENDO
ILO
32.5
32.8
33.0
33.5
34.0
34.3
34.5
> 34.5
< 34.1
34.0
34.5
< 33.5
34.0
34.5
35.0
35.4
34.7
34.9
35.0
35.1
35.3
34.8
34.9
35.0
35.3

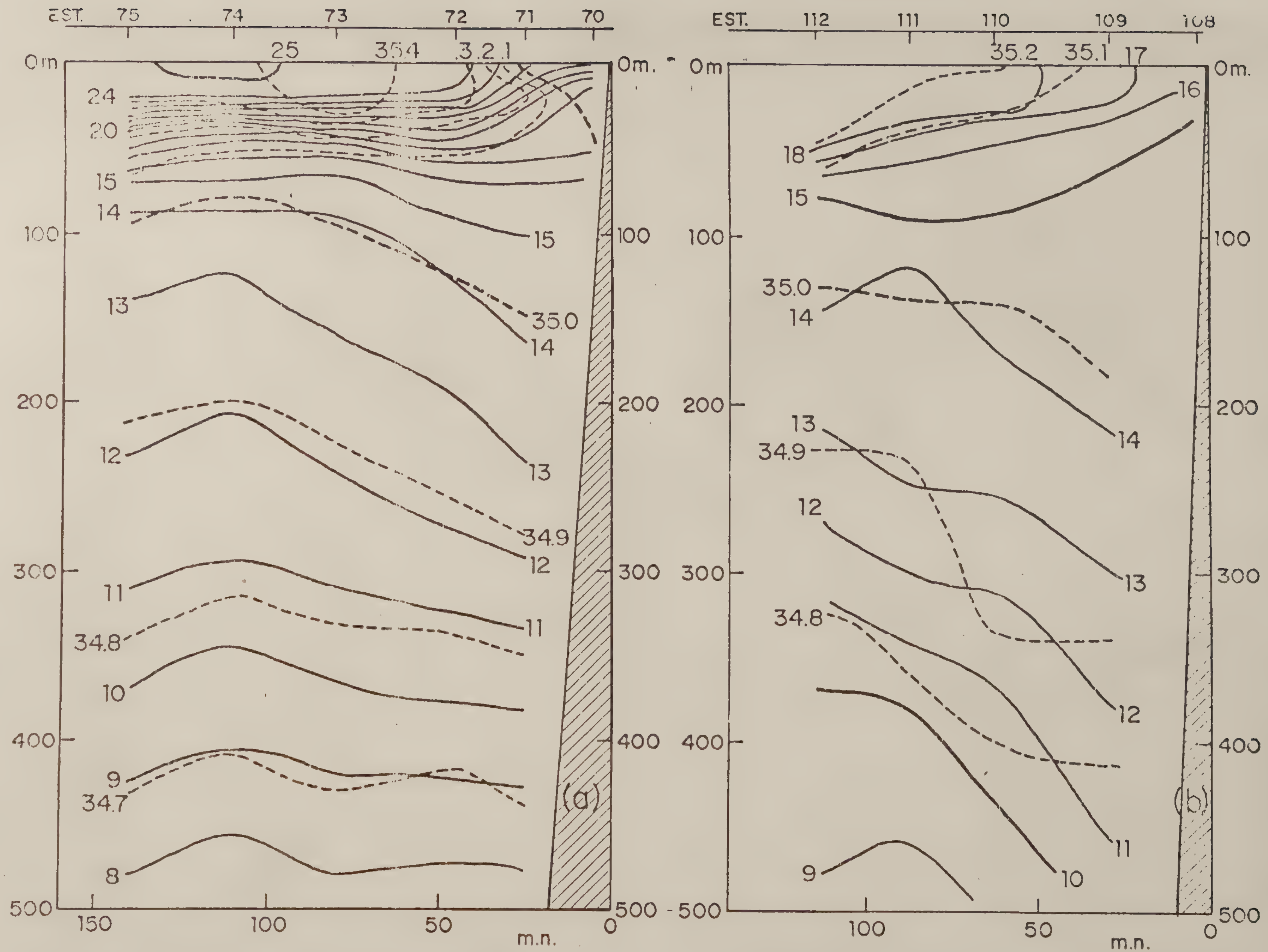


Crucero 7608 BAP UNANUE
10-30 Agosto 1976

S(‰) a 0m

Fig. 11 (b)

86°
84°
82°
80°
78°
76°
74°
72°
70°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
PTO. PIZARRO
CABO BLANCO
TALARA
PAITA
PUNTA FALSA
PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
SAN JUAN
ATICO
MOLLENDO
ILO
A
35.1
35.15
35.25
35.2
35.3
35.1
35.0
35.0
35.1
35.15
35.2
35.15
35.1
35.2



Sección T(—) y S(- - -) Pta.Falsa Cr.R/V Siedlecki
Enero 1980. (Cr.8001)

Sección T(—) y S(- -) Pta.Falsa Cr.BIC SNP-1
Setiembre 1980. (Cr.8008)

Fib. 12

c) Características de un período cálido o de El Niño. La distribución de la salinidad en un verano e invierno cálidos se da en las Figs. 11a y 11b.

En el verano de 1972, la costa peruana mostró un gran contraste. Al norte de los 10°S toda el área costera estaba cubierta con aguas de bajísima salinidad (32.8 a 34.8°/oo) procedentes de la región ecuatorial y se propagaba hacia el sur con el eje principal a 60-180 millas de la costa, a mayor distancia hacia el norte, y al parecer, parte de esta agua se proyectó hasta Pucusana dentro de las 20 millas de la costa (ver isohalina de 34.8°/oo). Al sur de los 10°S, las isohalinas de 35.1-35.4°/oo mostraron un acercamiento de las ASS a 40-60 millas de la costa entre Huarmey-Cerro Azul (10-13°S) y entre Pta. Doña María-Atico, y a 15 millas de la costa entre Mollendo-Ilo; es decir, que estas aguas estuvieron más pronunciadas al sur de los 15°S. Además, las isohalinas mostraron cierto paralelismo con la línea costera al sur de Huarmey (10°S). Entre los 9-10°S se situó parte de la frontera hídrica entre las aguas de la región subtropical y las de la región ecuatorial. Tanto al norte como al sur de los 10°S fueron apreciables las gradientes de salinidad; pero mucho más intensos en el lado norte, especialmente al norte de los 7°S.

En el invierno de 1976 las aguas con salinidades de 35.1 a 35.3°/oo cubrieron casi toda la costa en la parte observada entre los 5°30'-18°30'S, especialmente en agosto, y sólo en septiembre la isohalina de 35.0°/oo se extendió en forma apreciable entre Pta. Doña María-Arica y dentro de las 30 millas de la costa. Se trata pues de un invierno con gran influencia de aguas subtropicales superficiales (ASS); las cuales tuvieron un mayor impacto en la costa frente a Chimbote, Cerro Azul y Mollendo.

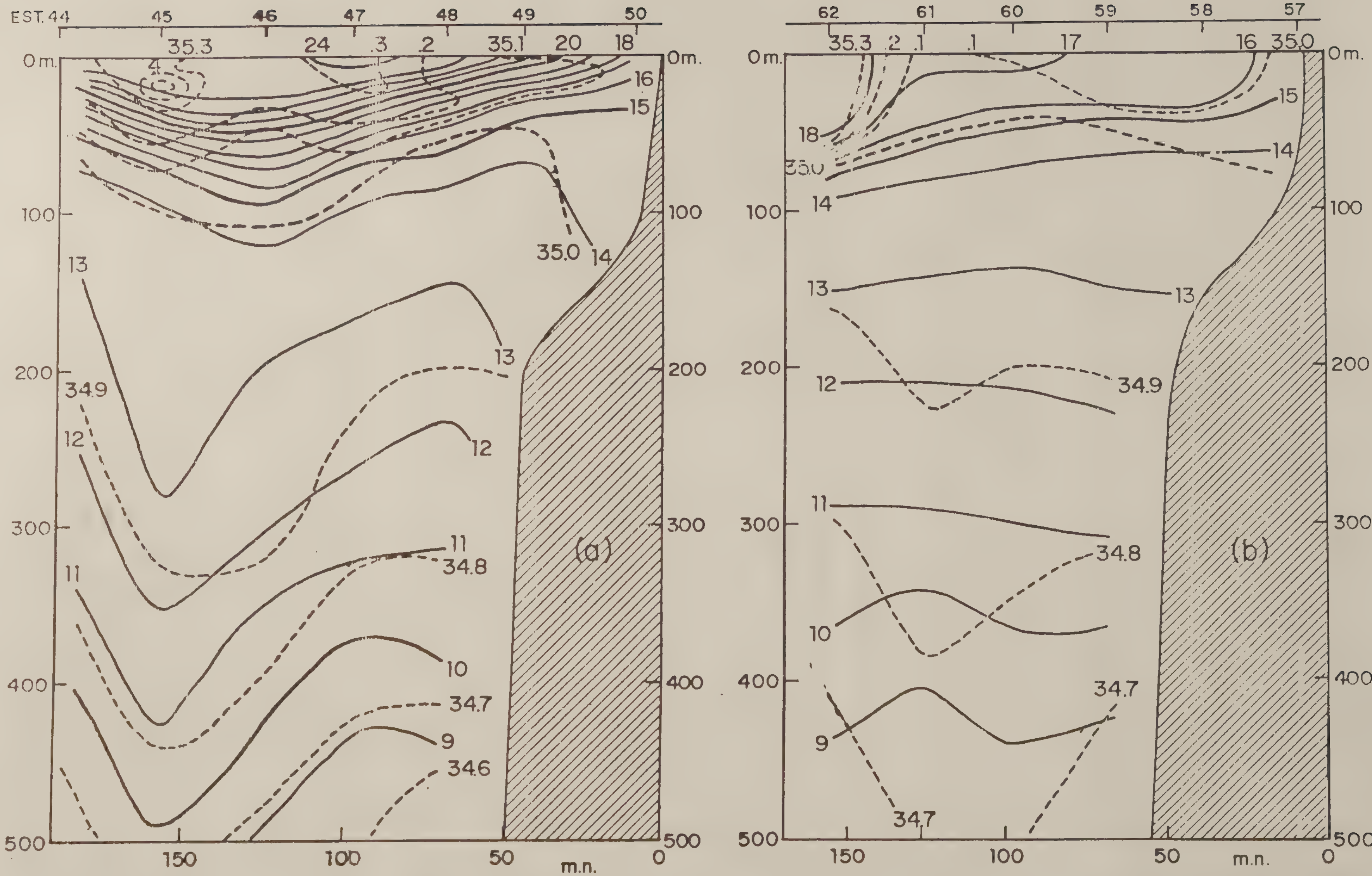
## Distribución Vertical de la Temperatura, Salinidad y Oxígeno

Las Figs. 12, 13, 14, 15 y 16 muestran las características generales de la distribución vertical de la temperatura (°C) y la salinidad (°/oo) en verano e invierno en cuatro lugares de la costa, aproximadamente a los 6°S, 10°S, 15°S y 18°S; y la Fig. 17 muestra la distribución vertical del oxígeno disuelto en el verano e invierno frente a Chimbote (9°S), Callao (12°S), San Juan (15°S) e Ilo (17°S). Se trata de destacar la capa de mezcla o napa, la capa de transición, la capa subsuperficial y la capa de mínima de oxígeno.

a) Estructura térmica. En el verano (Figs. 12a, 13a, 14a y 15a) la capa se presenta con 10 a 20 m de espesor y temperaturas mayores de 24°C. La termoclina se desarrolla por encima de los 60 y 100 m de profundidad, con 9 a 12 isotermas y se pega a la superficie cerca de la costa, dando lugar al gradiente intenso en la distribución horizontal a 0 m; además, en las secciones de San Juan y Pta. Coles, muestra dos gradientes, uno muy inteso en el lado superior y otro más moderado en el lado inferior; el primero producto del calentamiento estacional. La isoterma de 20°C se sitúa aproximadamente en el borde inferior del gradiente intenso o aproximadamente en el centro de la termoclina. La isoterma de 15°C se presenta en el borde inferior de la termoclina, tanto en Huarmey, San Juan y Pta. Coles; pero en Pta. Falsa se aparta de la termoclina, especialmente cerca de la costa y donde está presente la capa termostática asociada a la extensión sur de la Corriente Cromwell (Zuta y Guillén, 1970).

En la capa subsuperficial por debajo de la termoclina, se presentan las isotermas de 14-9°C entre los 100-500 m de profundidad, mostrando una tendencia a la estratificación, con un hundimiento hacia la costa dentro de los 100-300 m de profundidad (excepto frente a Pta. Coles) en asociación a flujos submarinos hacia el sur. El hundimiento de las isotermas de 10-13°C a 150 millas frente a Salaverry y a los 72°W frente a Pta. Coles, podría estar asociado a remolinos anticiclónicos que se desarrollan en la capa subsuperficial.

En el invierno (Figs. 12b, 13b y 16), el gradiente vertical se debilita notablemente por encima de los 100 m de profundidad, como consecuencia del enfriamiento estacional, quedando 3 a 5 isotermas (15-19, 14-16) como rezagos de la termoclina, en tanto que el espesor de la capa de mezcla aumenta notablemente hasta 50 y 125 m, asociada a la intensificación de los vientos invernales. Por debajo de los 100 m de profundidad los cambios son moderados, al parecer relacionados fundamentalmente con las variaciones en la intensidad de los flujos submarinos. La magnitud de los cambios es del orden de 1.0°C y no necesariamente de signo positivo (enfriamiento en el invierno).



Sección T(—) y S(---) Huarmey Cr. 8001 R/V Siedlecki
Enero 1980.

Sección T(—) y S(---) Huarmey Cr. 8008 BIC SNP-1
Agosto 1980.

Fig. 13

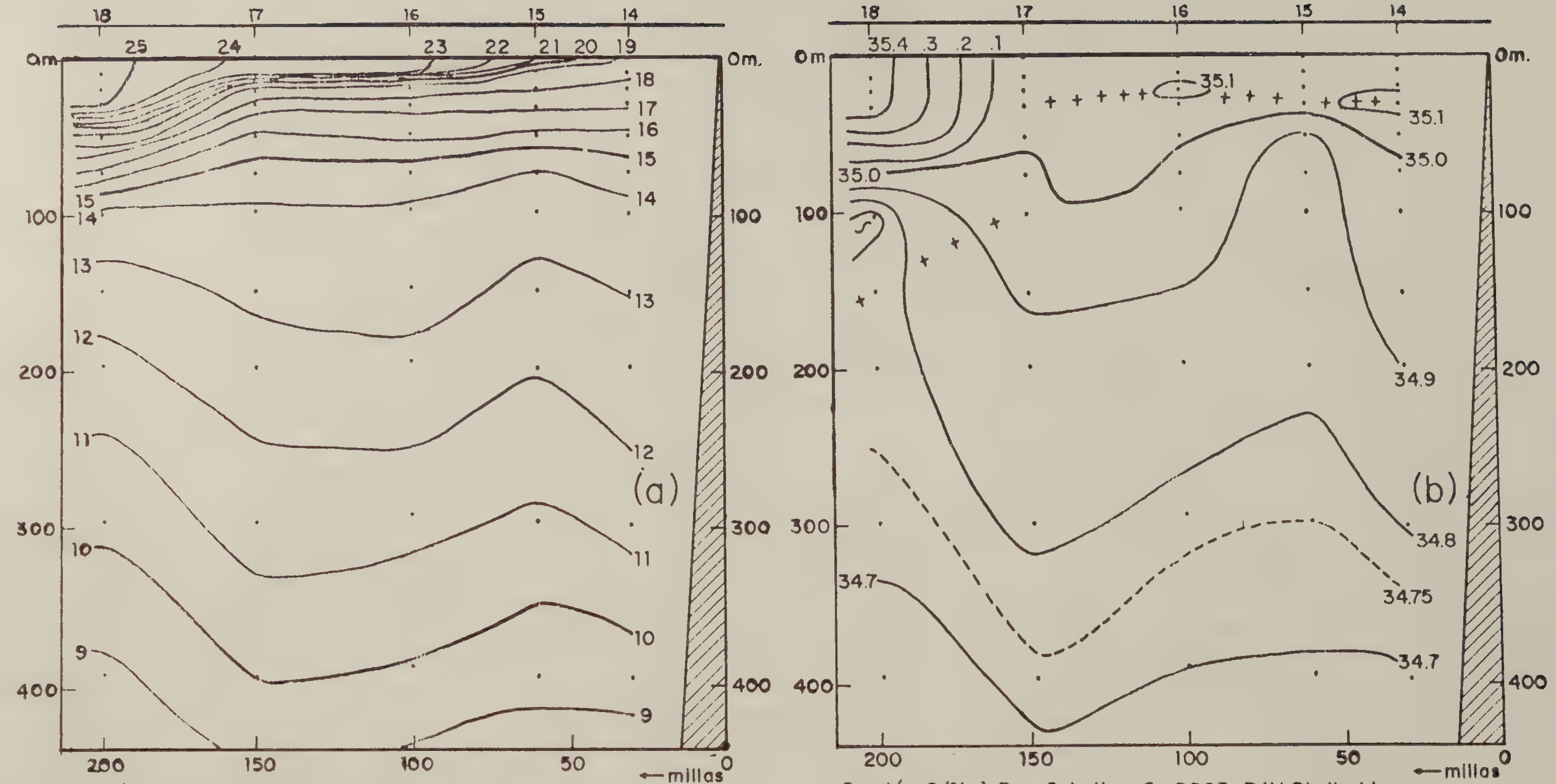
La estructura térmica depende grandemente de los cambios estacionales y de las corrientes sujetas a variaciones de diferente orden. En la capa subsuperficial, la capa relativamente más homogénea señalada por las isotermas de 12-15ºC está asociada a la presencia de la extensión sur de la Corriente Cromwell, la que da lugar al hundimiento de dichas isotermas cerca de la costa y es más intensa cuanto mayor sea la divergencia o separación entre las isotermas de 15 y 14ºC.

b) Estructura halina. Las Figs. 12a, 13a, 14b y 15b correspondientes al verano 1980, muestran una capa de transición apreciable (haloclina) por encima de los 40 y 80 m de profundidad, asociada a la termoclina, con valores de 35.1 a 35.4º/oo frente a Pta. Falsa y Huarmey, y valores de 35.0 a 35.5º/oo frente a Pta. Coles. En este último caso dentro de la termoclina veraniega. Frente a San Juan, la haloclina aparece más allá de las 150 millas de la costa, ya que la salinidad es más homogénea más cerca de la costa, al parecer como resultado del fortalecimiento del afloramiento. Por debajo de los 100 m de profundidad, las isohalinas de 34.7-35.0º/oo siguen en general la tendencia de las isotermas de 9-14ºC, excepto frente a San Juan y Pta. Coles, donde al parecer la interacción entre las aguas procedentes del norte y del sur producen bolsones y fluctuaciones de las isohalinas. En la sección de Pta. Coles se aprecia claramente una capa de salinidad mínima con el eje aproximadamente en el borde inferior de la termoclina, con dos bolsones, uno costero y de salinidades más bajas, y otro lejos de la costa alrededor de los 73ºW, que son indicaciones de la presencia del agua subantártica procedente de la costa chilena. Por debajo de la capa de mínima se presenta un máximo de salinidad entre los 80-200 m de profundidad y un gran bolsón de relativa alta salinidad cerca de los 72ºW, asociadas con el agua ecuatorial subsuperficial que avanza hacia el sur. El bolsón salino parece que produce la separación de los dos bolsones de baja salinidad. Dependiendo de la época, cualquiera de estas dos aguas pueden aparecer en la superficie en el proceso de afloramiento.

La situación del invierno se muestra en las Figs. 12b y 13b, en las que ya no se presenta la haloclina y la columna de agua es de un gradiente débil en salinidad. Los cambios en la distribución vertical dependen de la presencia de las aguas subtropicales superficiales (ASS), de las aguas ecuatoriales superficiales (AES), de las aguas ecuatoriales subsuperficiales y de las aguas subantárticas (ASAA). Las AES afectan fundamentalmente la capa de 0-30 m de profundidad al norte de los 6ºS, y las ASS pueden proyectarse hasta los 100-200 m de profundidad. La magnitud de los cambios puede ser hasta del orden de 0.3º/oo por encima de los 100 m de profundidad, y hasta del orden de 0.1º/oo en la capa subsuperficial descrita; es decir que los cambios son pequeños. La excepción es en la parte al norte de los 6ºS donde la aparición de AES produce cambios usuales hasta de 0.6º/oo en la capa superficial.

c) Distribución vertical del oxígeno. La Fig. 17 muestra, tanto en el verano como en el invierno, una pequeña capa superficial con los valores más altos de oxígeno disuelto, que está asociada a la capa de mezcla. Por debajo de la superficial relativamente homogénea, se presenta la capa de transición u oxiclina, en la que el oxígeno cae bruscamente hasta valores muy próximos a cero. La capa de mínima de oxígeno, con valores menores de 0.5 ml/L se presenta mayormente entre los 100-500 m de profundidad, especialmente en el invierno. En el verano parece profundizarse el tope superior, y esto es particularmente cierto al norte de los 9ºS, por efecto del agua que arrastra la extensión sur de la Corriente Cromwell con un relativo alto contenido de oxígeno (Zuta y Guillén, 1970). Por otro lado, la capa de mínima se aproxima más a la superficie cerca de la costa, en algunos casos hasta 25 m de superficie (ver Callao o San Juan). Es importanto observer que la capa de 200-500 m frente a Chimbote, de 150-400 m frente a Callao, de 50-400 m frente a San Juan, presenta valores muy cercanos a cero, especialmente en el verano. En el trabajo de Zuta y Guillén (1970) se puede ver, además, que la capa de mínima afecta notablemente la parte costera entre los 12-18ºS.

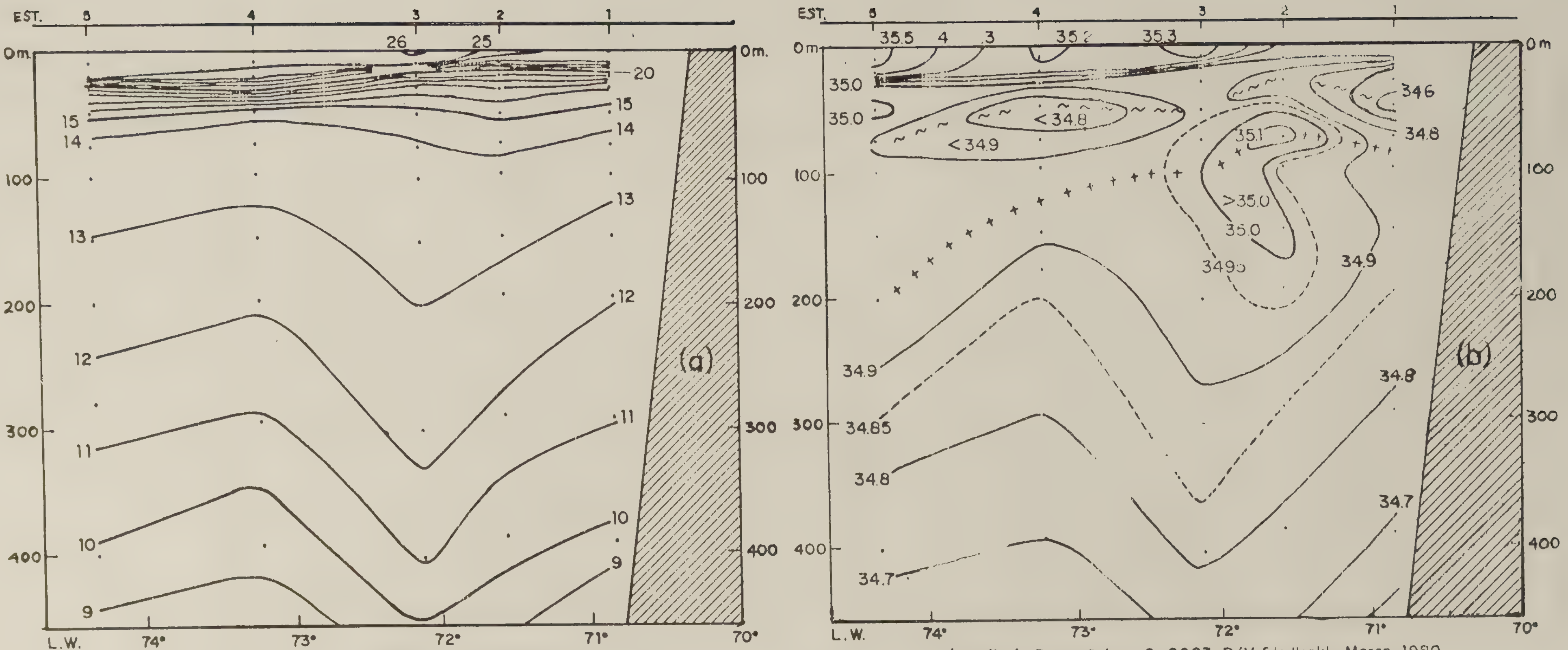
Aunque en este trabajo no se presentan datos de nutrientes, conviene mencionar que hay una relación entre la distribución de los nutrientes y la estructura térmica. Por ejemplo, los fosfatos, silicatos y nitratos presentan sus valores más bajos en la capa de mezcla o napa; aumenta rápidamente con la profundidad en la capa de la termoclina y lentamente en la capa subsuperficial (Zuta y Guillén, 1970).



Sección T (°C) Pta. Caballas Cr. 8003 R/V Siedlecki
Marzo 1980.

Sección S (‰) Pta. Caballas Cr. 8003 R/V Siedlecki
Marzo 1980.

Fig. 14



Sección T(°C) Punta Coles Cr. 8003 R/V Siedlecki Marzo 1980.

Sección S(‰) Punta Coles Cr. 8003 R/V Siedlecki Marzo 1980.

Fig. 15

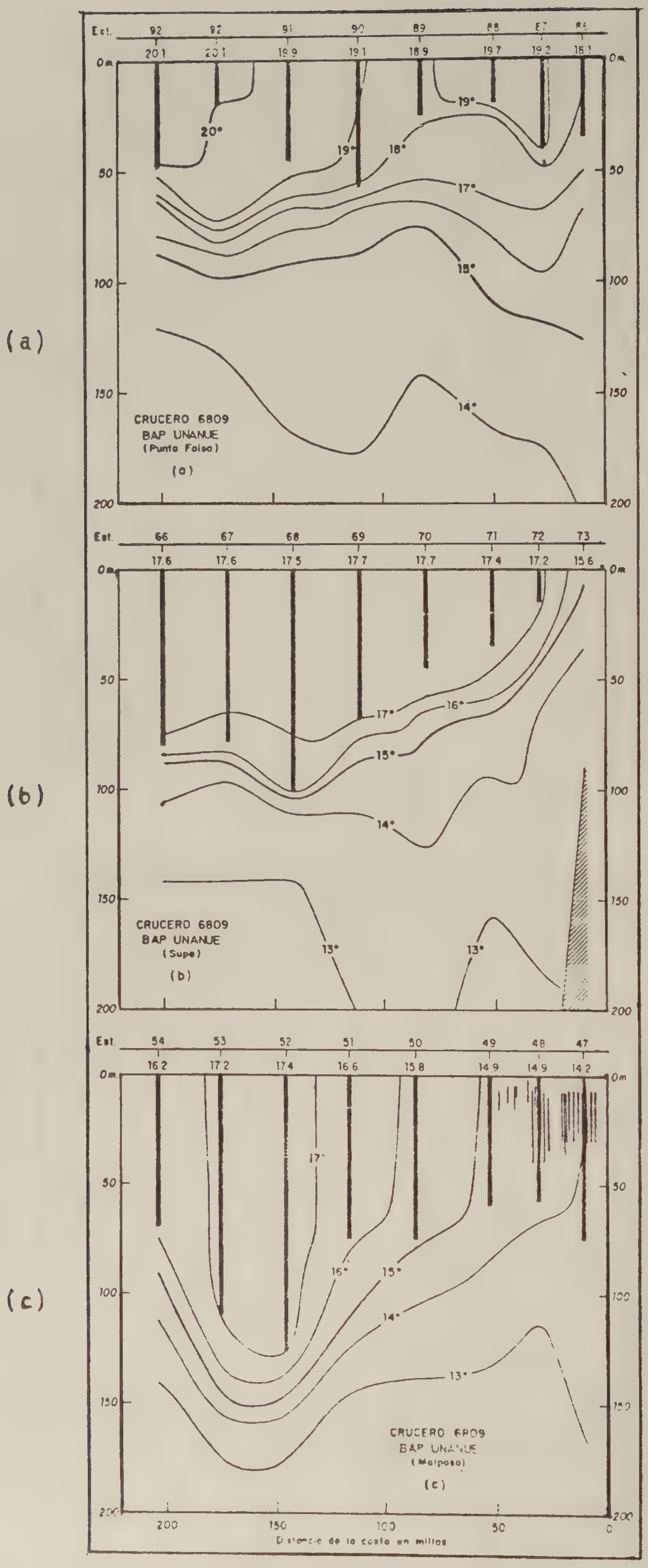


Fig. 16 : Secciones T(C)

## El Afloramiento y su Relación con las Corrientes y las Masas de Agua

Uno de los efectos más conocidos del afloramiento es la presencia en superficie de aguas con temperaturas relativamente bajas conformando lenguas frías que se proyectan lejos de la costa, asociadas a un alto contenido de nutrientes (Fig. 18). En las Figs. 5b, 6b, 8b y 9b se destacan las áreas de afloramiento frente a Paita (5ºS) y San Juan (15ºS), esta última de mayor permanencia aún en períodos de El Niño (Fig. 10a). El afloramiento se produce por encima de los 100 m de profundidad (Figs. 12, 13, 14, 15) y es alimentado principalmente por las aguas ecuatoriales subsuperficiales (AESS) que son arrastradas por la corriente submarina procedente de la zona ecuatorial; pero al sur de los 12ºS y espcialmente al sur de los 14ºS también es alimentado por las aguas subantárticas procedentes de la costa chilena. Hay pues dos fuentes principales que alimentan el afloramiento costero.

Las Figs. 19 (a, b, c) muestran unos diagramas compuestos de las cuatro estaciones del año para las áreas de Cabo Blanco (4ºS), Callao (12ºS) y San Juan (15ºS). Frente a Cabo Blanco, la dispersión de los puntos ocurre por encima de los 14ºC en el verano y la primavera, y por encima de los 16ºC en otoño e invierno; a menores temperaturas, las curvas mantienen las mismas características: presentan una porción aproximadamente recta hasta los 6ºC, y luego una curvatura con el incremento de salinidad. La porción recta con temperaturas de 6 a 16 (14)ºC y salinidades de 34.58 a 35.20º/oo, constituye la masa de agua denominada por Wyrtki (1963) agua ecuatorial subsuperficial (AESS), resultante de la mezcla del agua subtropical superficial (ASS) y el agua antártica intermedia (AAI). Esta masa de agua está presente a lo largo de toda la costa peruana y es la principal fuente del afloramiento costero. Desde luego que en su desplazamiento hacia el sur sufre ciertos cambios, como por ejemplo, frente a San Juan el AESS está pura entre 6-11ºC, pero entre los 11-16ºC entra en interacción con el agua subantártica de baja salinidad y también recibe más influencia del AAI, por lo que sus rangos de temperatura y salinidad varían (6-14ºC y 34.5-35.0º/oo).

El agua subantártica (ASAA) ingresa a la costa peruana entre 100-150 m de profundidad con salinidades de 34.6-34.8º/oo, constituyendo un mínimo entre las ASS y las AESS, y suele aflorar al sur de los 14ºS, particularmente en el invierno.

El sistema de corrientes frente al Perú está constituido por corrientes superficiales y submarinas, sobre las cuales se tiene un conocimiento muy general y se conoce poco de su variabilidad; pero se trata evidentemente de corrientes débiles con velocidades generalmente menores de 25 cm/seg. Hoy en día se está revisando la denominación de corrientes (Tomczak, 1981); pero para nuestro propósito usaremos la terminología de Wyrtki (1963): Corriente Costera Peruana (CCP), Corriente Oceánica Peruana (COP), Corriente Submarina (CSM), Contracorriente Peruana (CCCP) y Contracorriente Surecuatorial (CCSE), que le dan un panorama complejo al sistema (Fig. 20), y la complejidad parece surgir al este de los 90ºW, donde se producen deflecciones de la corriente peruana y formación de remolinos, según podemos ver en la Fig. 21 de Paul et al. (en prensa). Mediciones directas hechas en la Operación ESACAN y JOINT-II (Brockmann et al., 1980) muestran que la CSM es un fenómeno prominente del margen continental a lo largo de toda la costa peruana y de gran importancia para el afloramiento costero por tener su flujo principal encima de los 100 m de profundidad, mayormente entre los 40-80 m de profundidad, y por tener su origen al parecer en la propagación de la Corriente Cromwell rica en contenido de oxígeno (Cochrane y Zuta, 1968).

La corriente costera peruana (CCP) y la corriente oceánica peruana (COP) están sujetas al régimen de los alisios del sureste (ASE) y consecuentemente se debilitan en el verano y se intensifican en el invierno, alcanzando velocidades del orden de los 30 cm/seg (15 mn/día) en los meses de agosto-septiembre (ver cartas de Wyrtki, 1965) y es en estos meses que las dos corrientes se constituyen en un sólo flujo, hacia el noroeste.

Pero trabajando en una escala regional se puede apreciar mejor los remolinos y los meandros a lo largo de la costa, como se puede ver en la topografía de 15ºC que da una idea del flujo superficial predominante (Figs. 22a, b, c) y aún en la topografía de la capa de mezcla (Fig. 23a, b).

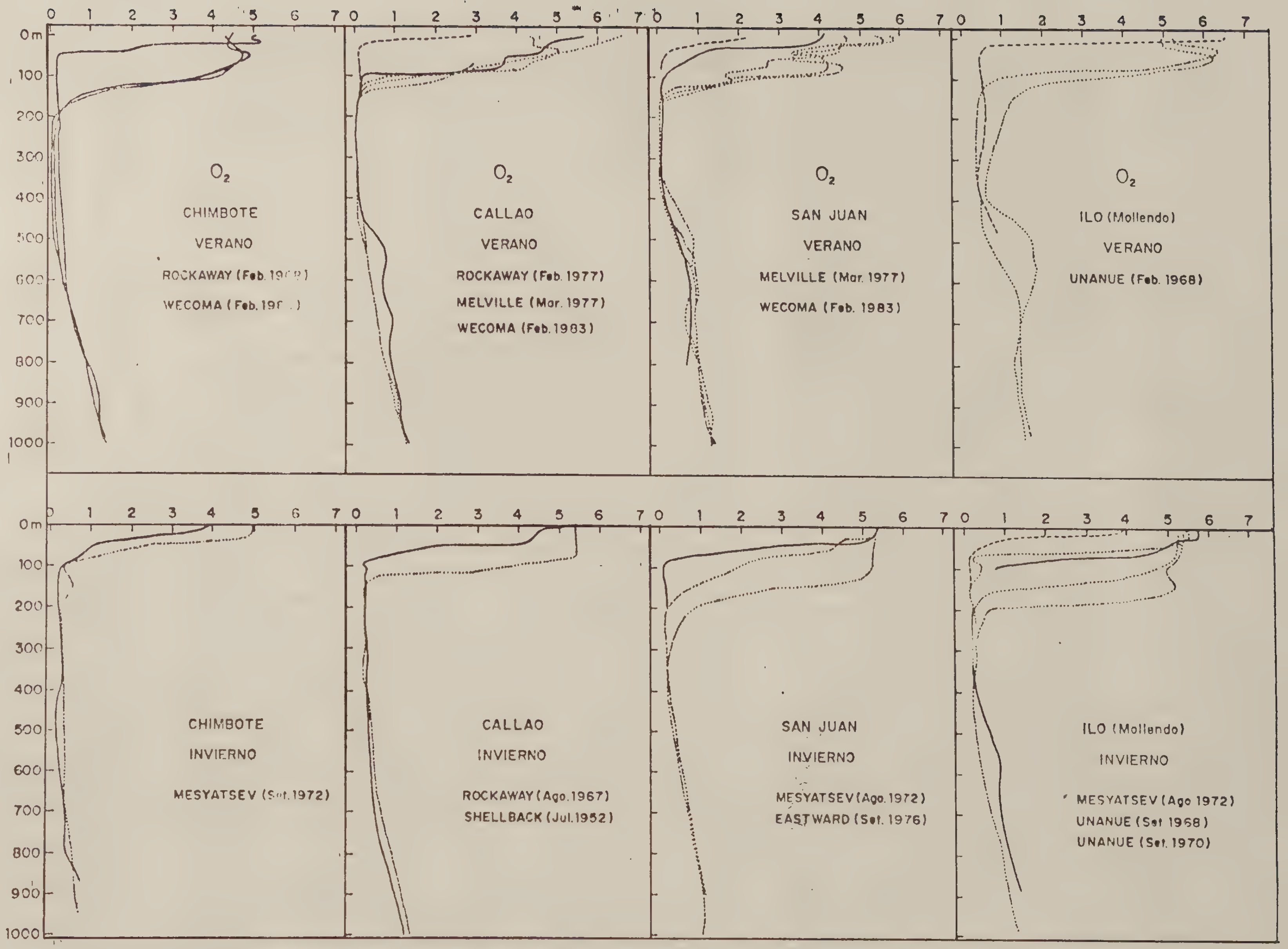
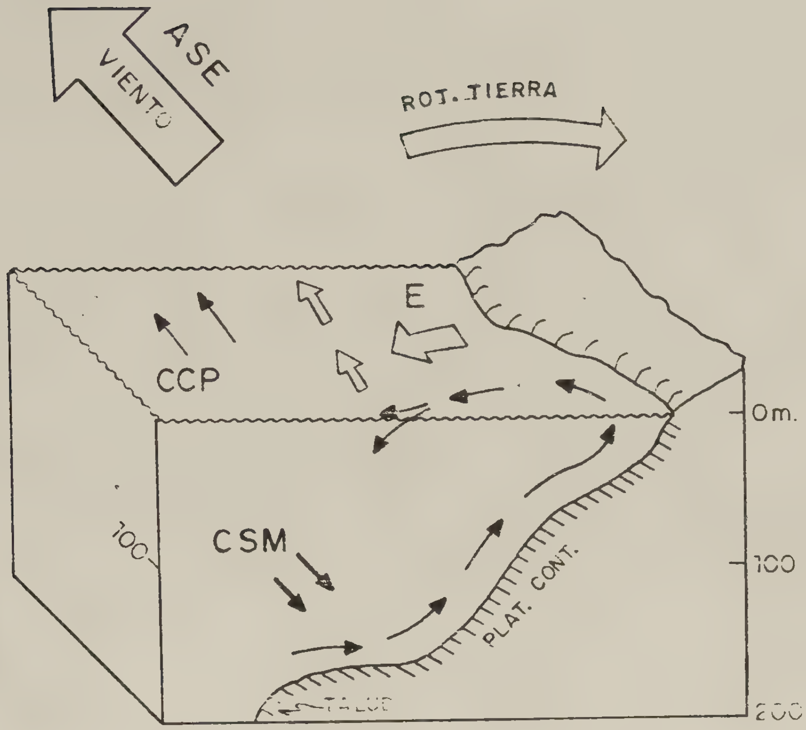


Fig. Distribución Vertical del contenido de OXIGENO (ml/L) en Verano (2,3) e Invierno (7, 8, 9) frente a Chimbote (9°S), Callao (12°S.), San Juan (15°S.) e Ilo (18 S.)
LEYENDA: Costero (----), Proximo (——), Lejano (·······), Distante (·······).

Fig. 17


ASE
VIENTO
ROT. TIERRA
E
CCP
CSM
100
0m.
100
200
PLAT. CONT.
TALUD

AFLORAMIENTO COSTERO

Fig. 18

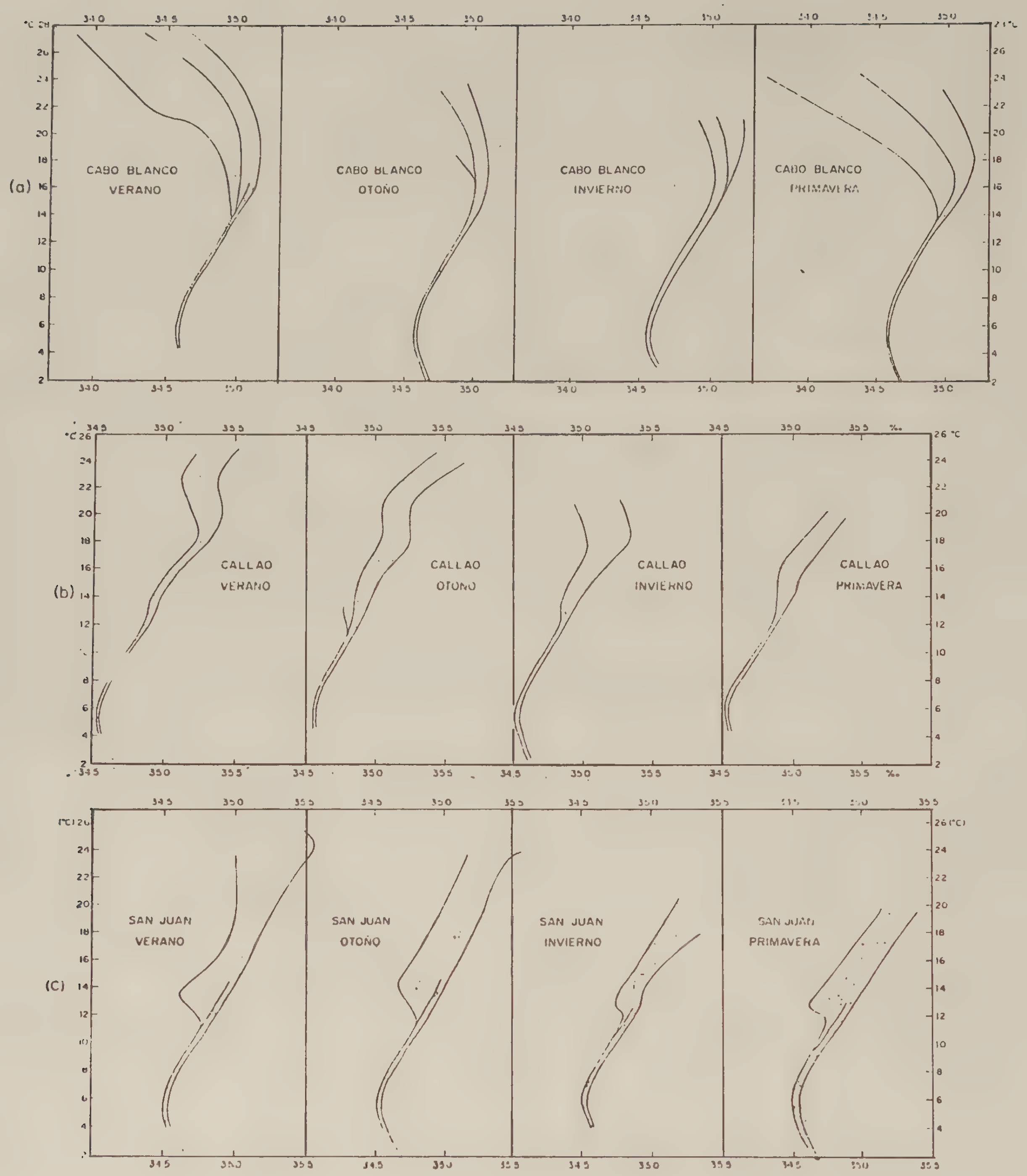
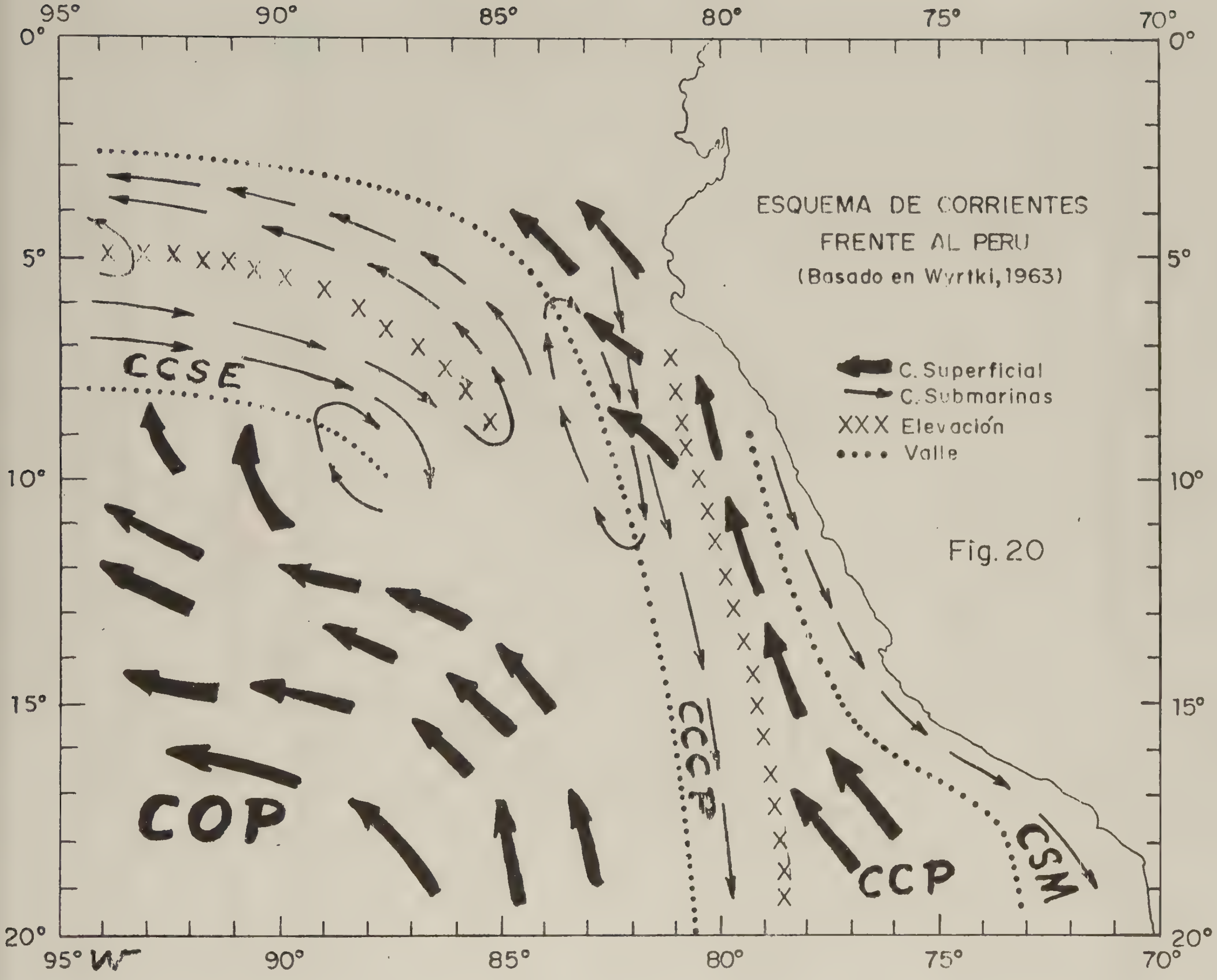


Fig. 19. Diagramas T-S en áreas seleccionadas de la costa peruana.



ESQUEMA DE CORRIENTES FRENTE AL PERU
(Basado en Wyrtki, 1963)

Fig. 20

C. Superficial
C. Submarinas
XXX Elevación
•••• Valle
CCSE
COP
CCCP
CCP
CSM
95°
90°
85°
80°
75°
70°
95° W
0°
5°
10°
15°
20°

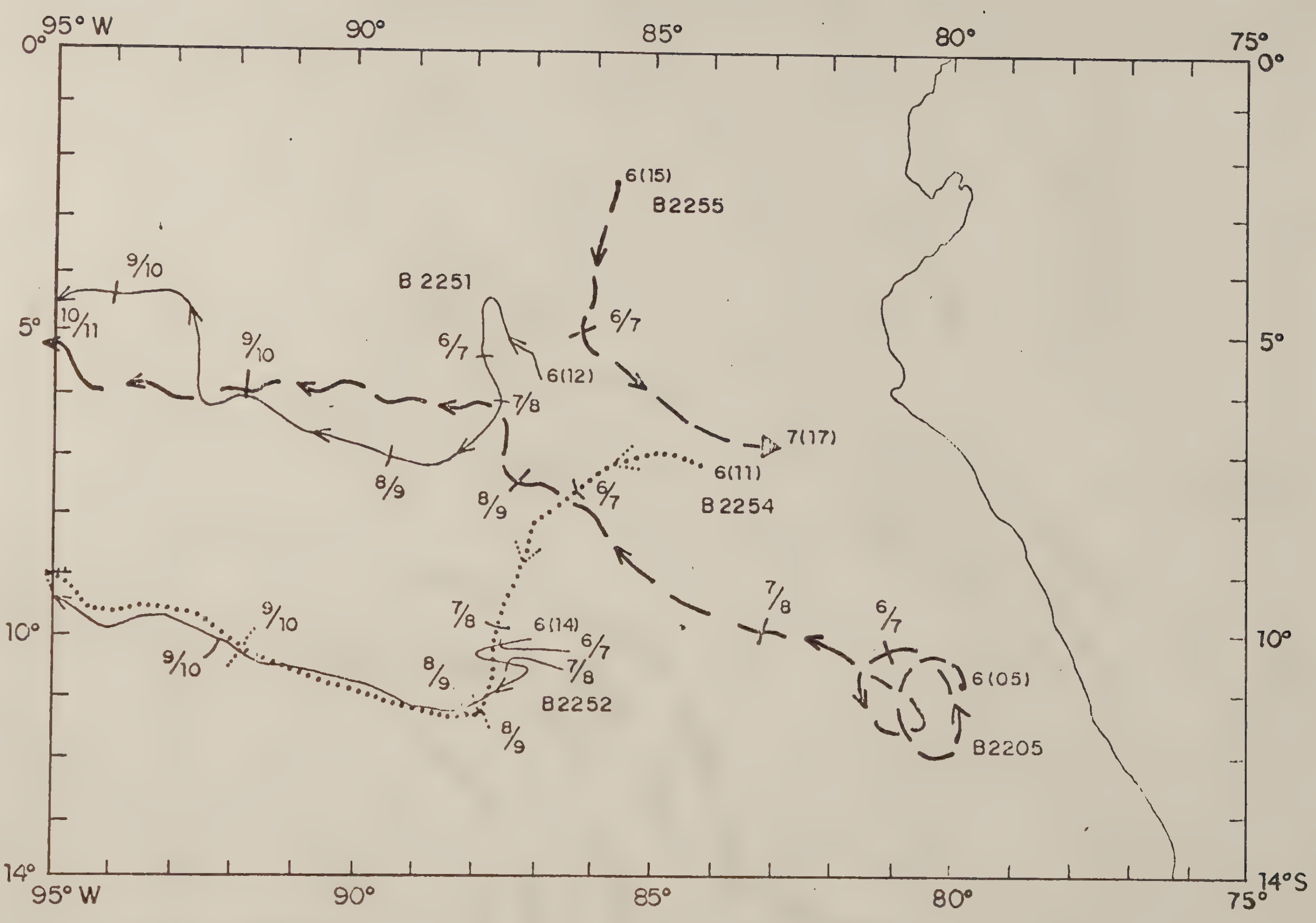
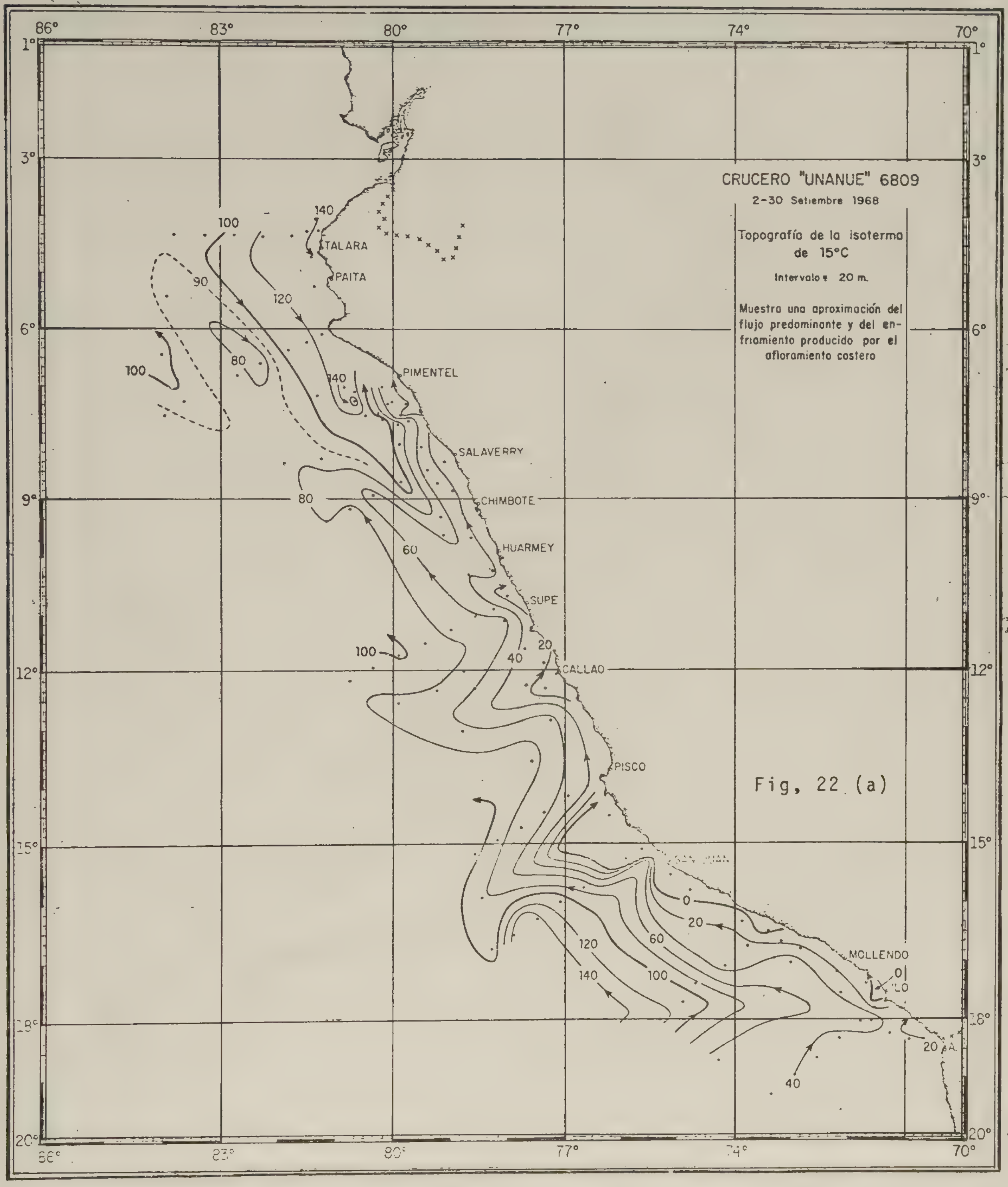
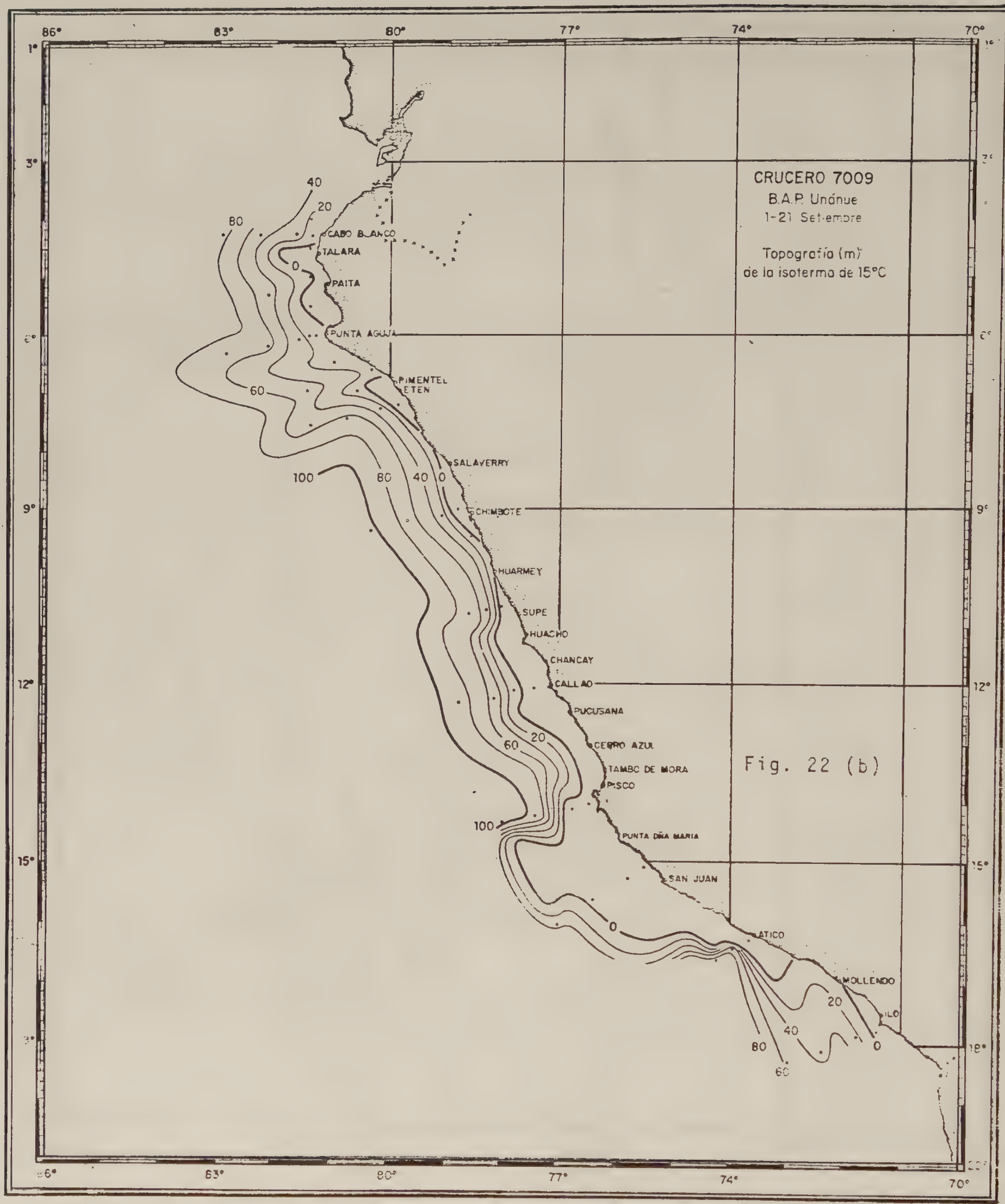

0°
95° W
90°
85°
80°
75°
0°
5°
10°
14°
14°S
95° W
90°
85°
80°
75°
5°
10°
6(15)
B2255
6/7
7(17)
B 2251
6/7
6(12)
7/8
9/10
9/10
10/11
8/9
8/9
6(11)
B 2254
6/7
7/8
6/7
6(05)
B2205
7/8
6(14)
6/7
7/8
B2252
8/9
8/9
9/10
9/10

Fig. Trayectoria de boyas oceanográficas lanzadas en Junio de 1979 durante el Cr. 7905 del BIC SNP-1.

Fig. 21


CRUCERO "UNANUE" 6809
2-30 Setiembre 1968
Topografía de la isoterma de 15°C
Intervalo = 20 m.
Muestra una aproximación del flujo predominante y del enfriamiento producido por el afloramiento costero
86°
83°
80°
77°
74°
70°
1°
3°
6°
9°
12°
15°
18°
20°
TALARA
PAITA
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
CALLAO
PISCO
SAN JUAN
MOLLENDO
ILO
A.
140
100
90
120
80
100
140
80
60
100
40
20
0
20
60
120
140
100
0
20
40

Fig, 22 (a)



CRUCERO 7009
B.A.P. Unánue
1-21 Setiembre

Topografía (m)
de la isoterma de 15°C

Fig. 22 (b)

86°
83°
80°
77°
74°
70°
1°
3°
6°
9°
12°
15°
18°
40
20
80
0
60
100
80
40
0
20
60
100
0
20
40
80
60
0
CABO BLANCO
TALARA
PAITA
PUNTA AGUJA
PIMENTEL
ETEN
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
SAN JUAN
ATICO
MOLLENDO
ILO

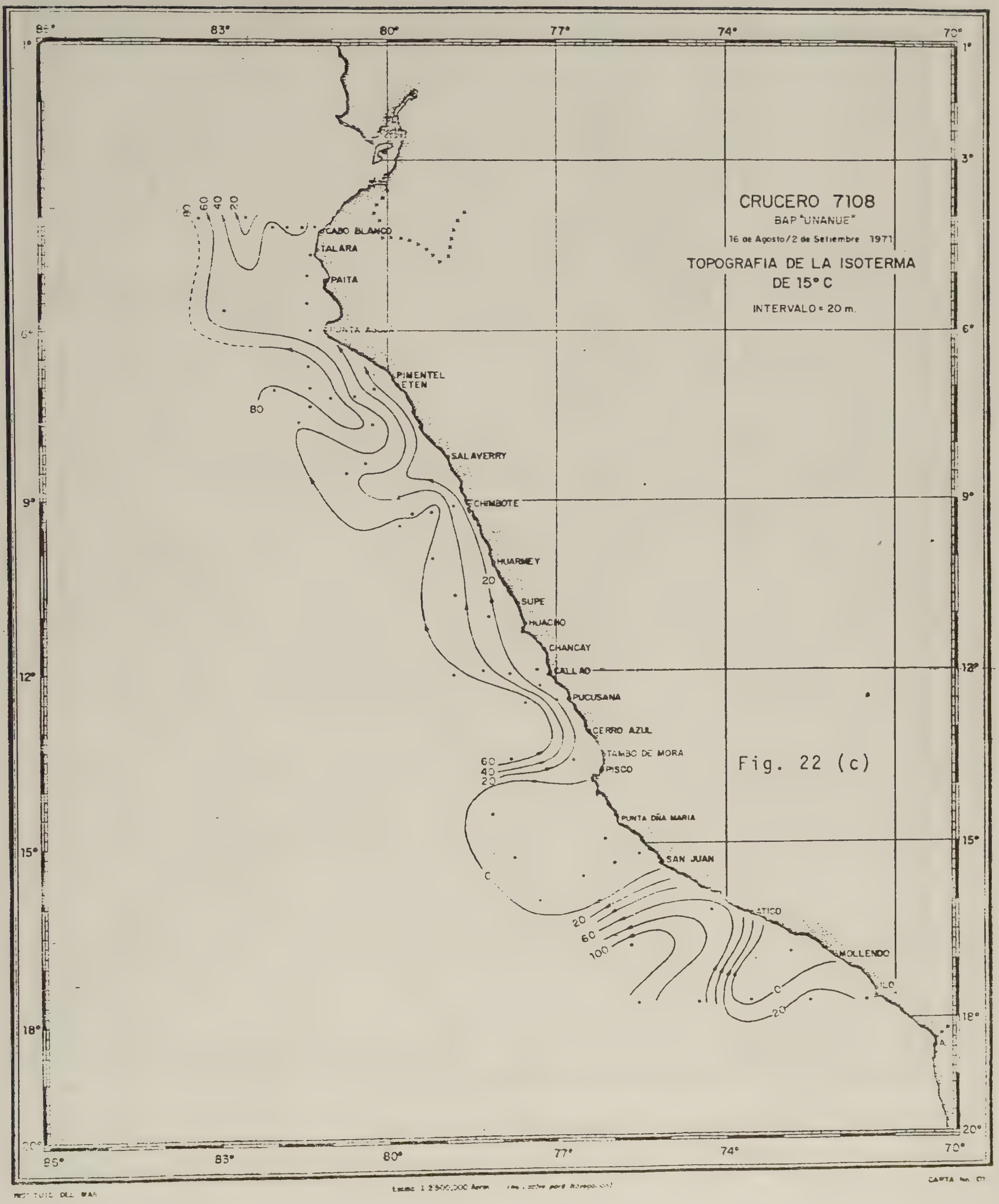
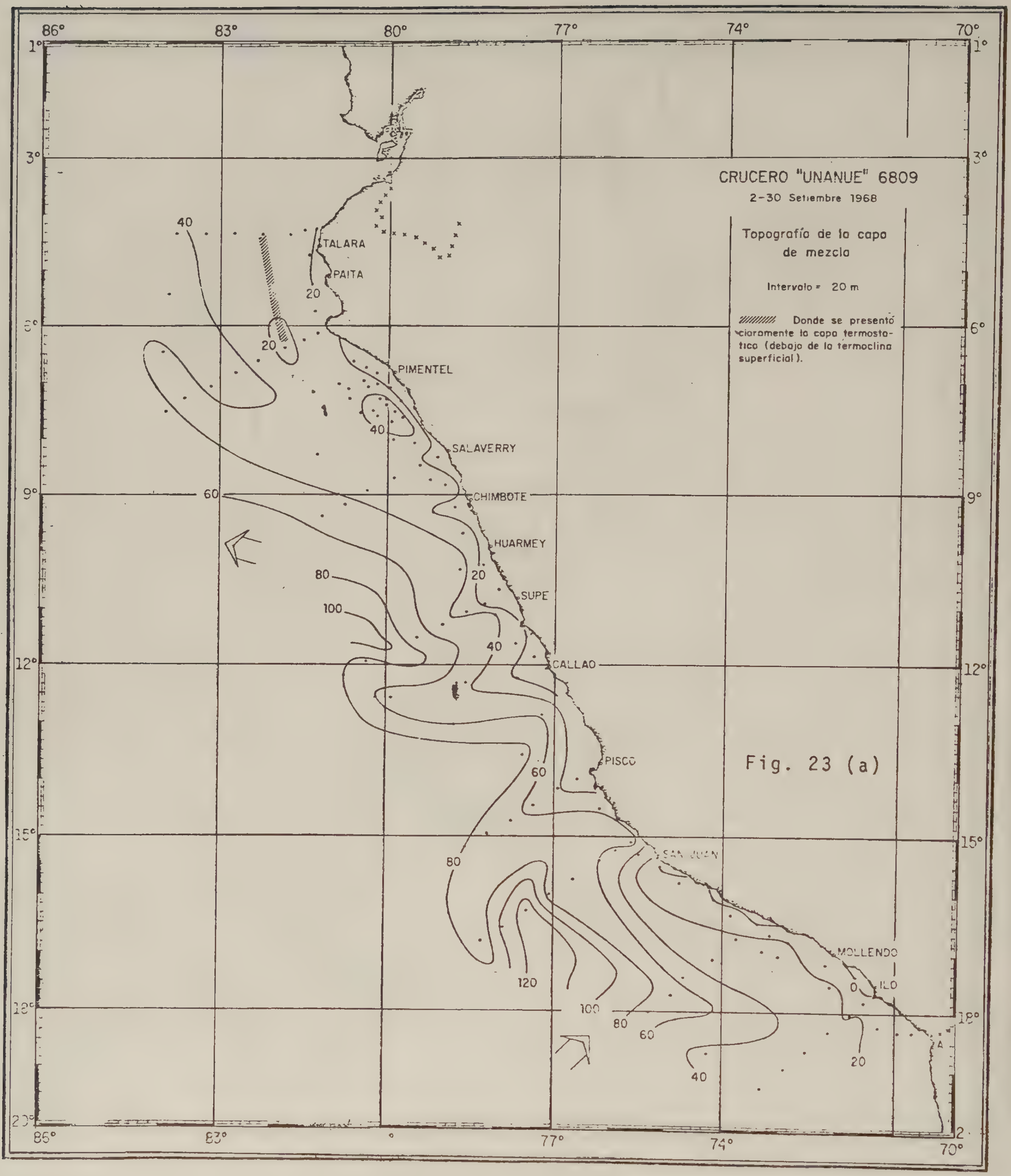

CRUCERO 7108
BAP "UNANUE"
16 de Agosto/2 de Setiembre 1971
TOPOGRAFIA DE LA ISOTERMA
DE 15° C
INTERVALO = 20 m.
CABO BLANCO
TALARA
PAITA
PUNTA AGUJA
PIMENTEL
ETEN
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA MARIA
SAN JUAN
ATICO
MOLLENDO
ILO
86°
83°
80°
77°
74°
70°
1°
3°
6°
9°
12°
15°
18°
20°
80
60
40
20
100
0
INSTITUTO DEL MAR

Fig. 22 (c)



CRUCERO "UNANUE" 6809

2-30 Setiembre 1968

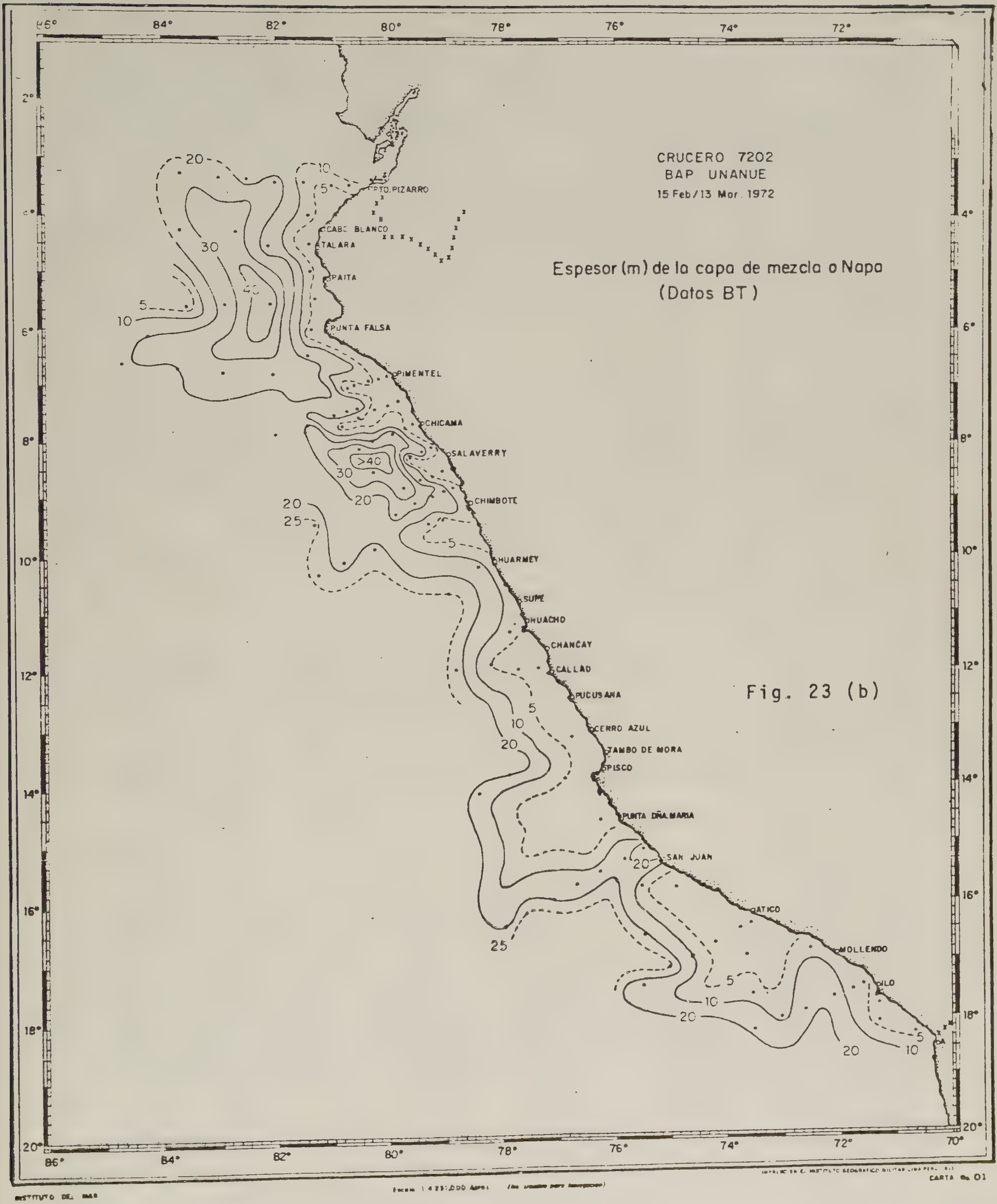
Topografía de la capa de mezcla

Intervalo = 20 m

▨ Donde se presentó claramente la capa termostatica (debajo de la termoclina superficial).

Fig. 23 (a)

86°
83°
80°
77°
74°
70°
1°
3°
6°
9°
12°
15°
18°
20°
TALARA
PAITA
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
CALLAO
PISCO
SAN JUAN
MOLLENDO
ILO
20
40
60
80
100
120
0



CRUCERO 7202
BAP UNANUE
15 Feb/13 Mar. 1972

Espesor (m) de la capa de mezcla o Napa
(Datos BT)

Fig. 23 (b)

86°
84°
82°
80°
78°
76°
74°
72°
70°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
PTO. PIZARRO
CABO BLANCO
TALARA
PAITA
PUNTA FALSA
PIMENTEL
CHICAMA
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
HUACHO
CHANCAY
CALLAO
PUCUSANA
CERRO AZUL
TAMBO DE MORA
PISCO
PUNTA DÑA. MARIA
SAN JUAN
ATICO
MOLLENDO
ILO
5
10
20
25
30
40
>40
INSTITUTO DEL MAR
CARTA No 01

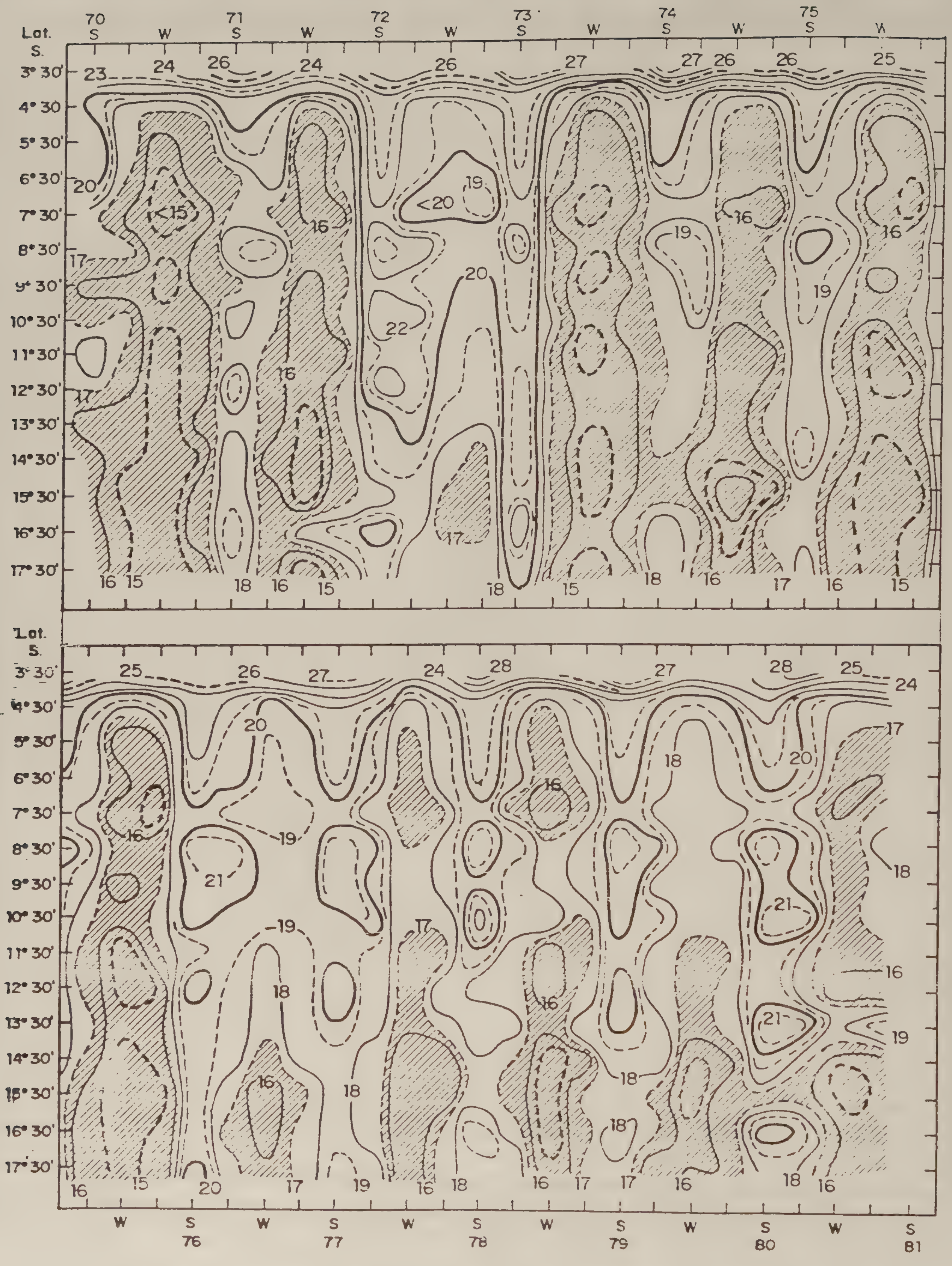


Fig. Variaciones estacionales de TSM a lo largo de la Costa Peruana, en el periodo 1970-1981.
S = Verano (Summer) y W = Invierno (Winter).

Fig. 24

### Variaciones Interanuales

La costa peruana está grandemente influenciada por fenómenos de macroescala, los cuales introducen cambios en períodos irregulares de tiempo. Las Figs. 24 y 25 muestran una secuencia de años fríos, calientes y moderados a lo largo de toda la costa, destacándose los períodos fríos de 1970-71,1973-75 y los años calientes de 1972 y 1976. En esta secuencia, la primavera (oct-dic) de 1975 y el verano de 1976 presentan salinidad baja en la franja costera, particularmente de los 10$^{o}$S hacia el norte, asociada en este último caso con la propagación hacia el sur de AES. En cambio, el otoño de 1977 (post-Niño) y la primavera de 1981 (pre-Niño) presentan salinidades altas en gran parte de la costa peruana. Se nota un predominio de las salinidades altas al norte de los 11$^{o}$30'S, un predominio de las salinidades bajas al norte de los 5$^{o}$30'S y un predominio de salinidades medias (alrededor de 35.0$^{o}$/oo) a los 15$^{o}$30'S. Las grandes variaciones ocurren a los 4$^{o}$30'S; pero también hay variaciones interanuales importantes a los 18$^{o}$30'S. La parte entre los 6-14$^{o}$S es dominada por ASS, con excepción de los veranos de 1976, 1979 y 1982 de bajas salinidades al norte de los 10$^{o}$30'S.

De las variaciones interanuales, lo más trascendente y hasta espectacular es la ocurrencia del Fenómeno El Niño o evento El Niño, el cual se manifiesta en el mar con grandes calentamientos que duran de 10 a 14 meses, cambios temporales en la circulación superficial y subsuperficial, etc. La serie de tiempo de la Fig. 4 muestra los períodos de El Niño de 1925, 1941, 1957, 1965, 1972, y 1976; y las Figs. 3, 26 y 27 muestran aspectos importantes del evento El Niño 1982-83 que se presentó con características muy especiales, entre los que mencionaremos lo siguiente: inicio del calentamiento en el invierno, anomalías térmicas positivas predominantes de 3 a 7$^{o}$C, temperaturas superficiales hasta de 31$^{o}$C muy cerca de la costa y propagación de AES hasta cerca de los 14$^{o}$S. En la atmósfera las precipitaciones asociadas al evento han superado también a eventos anteriores, con daños materiales estimados hasta abril de 1983 en el orden de los 600 millones de dólares, más las pérdidas de vidas humanas a raíz de los huaycos, problemas de salud, de alimentación, de transporte y paralización de varias actividades. El evento en actual evolución ha desconcertado a la comunidad oceanográfica y meteorológica mundial y se tiene que revisar muchas de las teorías existentes (Wyrtki, 1981; Rasmusson y Carpenter, 1982; Enfield, 1980; Busalacchi, Jr., 1982; etc.) y hay la necesidad de coordinar las investigaciones y el monitoreo del océano y la atmósfera a nivel internacional, dentro de una gran comunidad de esfuerzo que permita lograr una previsión de los cambios y un mejor uso de los recursos.

Las características descritas en este capítulo sobre el ambiente, sirven de marco para interpretar la distribución y la fluctuación de los recursos pesqueros.

## LOS RECURSOS PESQUEROS Y SUS VARIACIONES

### Cambios en la Distribución de los Recursos Pelágicos

Tal como lo expresa Sharp (1981) quizás las mejores indicaciones del estado del recurso están dadas por el área de distribución (o volumen) y la abundancia o tamaño de las agregaciones dentro de este rango, recalcando la necesidad de emplear datos independientes de la pesquería puesto que la flota opera de preferencia sobre determinadas especies y en ciertas áreas, cuyas condiciones facilitan una alta vulnerabilidad a través de las agregaciones. En este sentido, a fin de mostrar las variaciones estacionales y anuales de los principales recursos pelágicos, se han analizado los datos de capturas registradas durante las prospecciones científicas de IMARPE. Todas las calas analizadas se han efectuado en la capa superficial (sobre 100 m de profundidad) y hasta una distancia máxima de 100 millas de la costa.

En las Figs. 28 (a, b) y 29 (a, b) se presenta la distribución de la anchoveta, sardina, jurel y caballa en series de tiempo estacional, a lo largo de la costa peruana, cubriendo el período de invierno 1972 a verano 1983 (este último sólo para el sur de los 12$^{o}$S). Se han trazado isolíneas que indican el porcentaje en que cada especie estuvo representada en las capturas (en peso), en relación con las capturas de todas las especies, en el total de calas efectuadas por grado de latitud y estación. En consecuencia, este porcentaje que indica el grado de dominancia relativa de cada especie, en cierta medida puede tomarse como un índice de la agregación de cardúmenes. Como la sardina y anchoveta forman agregaciones más compactas que el jurel y la caballa, se han acentuado para dichas especies el sombreado de áreas con valores mayores del 50% de las capturas en peso, mientras que para el jurel y caballa se han acentuado el sombreado de áreas con más del 20%.

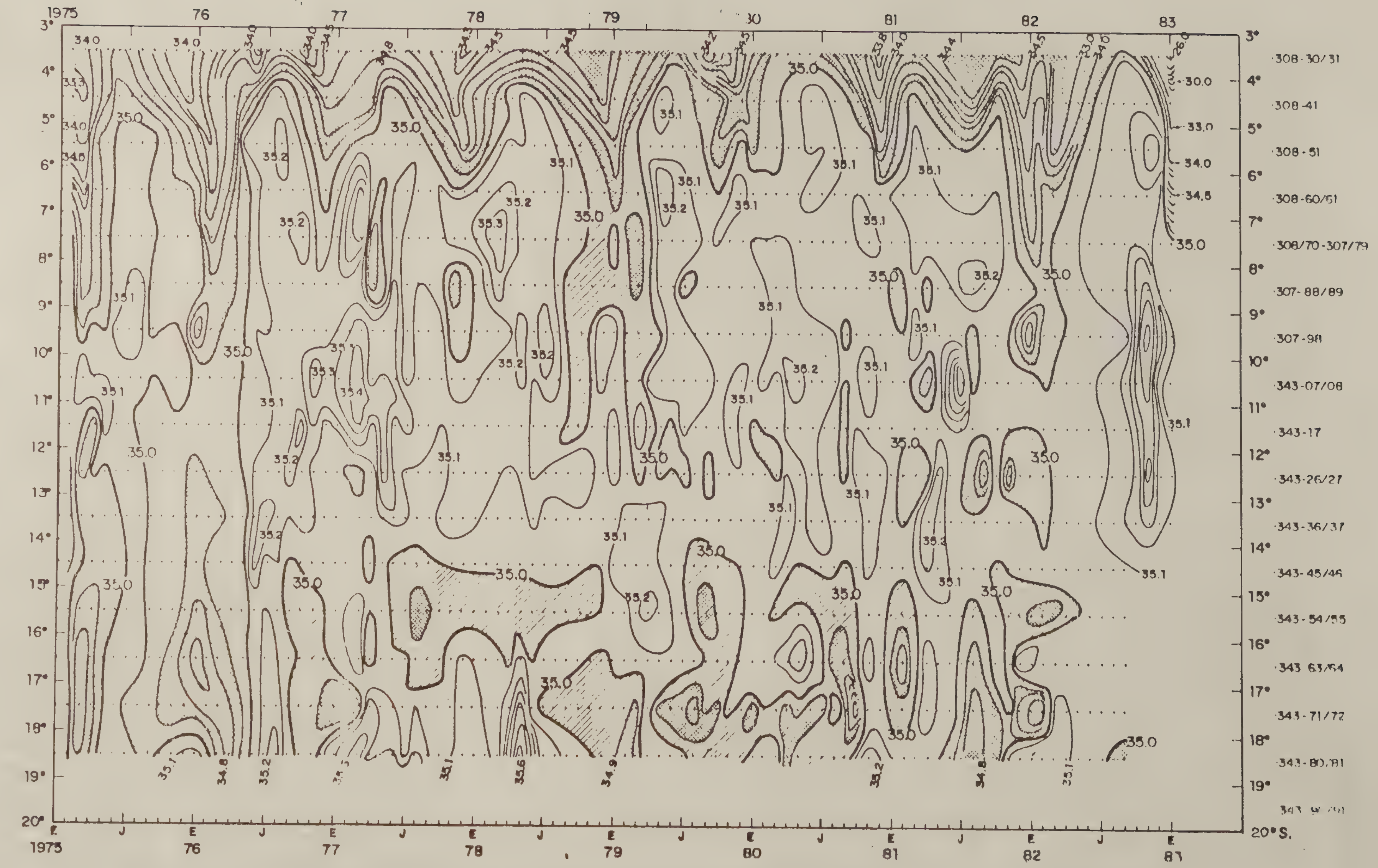


Fig. Variaciones de la SSM(‰) a lo largo de la costa peruana durante el periodo 1975-1983. (La parte clara con valores mayores de 35‰ y el intervalo general de isohalinas es de 0.1 ‰).

Fig. 25

Anchoveta. La Fig. 28 (a) muestra la distribución de anchoveta, donde se aprecia que entre el otoño 1973 y primavera 1976, la distribución es comparativamente más amplia que durante los otros períodos, al mismo tiempo que exhibe mayores focos de agregación, destacándose en los 14°S un foco constituido por anchoveta sin mezcla con otras especies, durante el invierno-primavera de 1976.

Los focos de alta agregación están asociados con la preferencia de los cardúmenes por las aguas costeras en la zona de transición entre las aguas frías con las calientes subtropicales, con salinidades de 35.0-35.1°/oo.

En contraste con esta situación, durante El Niño 1972-73, ésto es, en el invierno de 1972, la distribución de anchoveta abarca áreas más reducidas, donde la mayor agregación se localiza en los 10-11°S y en la siguiente estación de primavera 1973, se reduce aún más ubicándose en el extremo sur, lo cual corrobora el desplazamiento del stock hacia zonas más favorables observado también en la pesquería de dicho período. En El Niño de 1976-77 también se observa un hecho similar aunque en menor grado, cuando la anchoveta se distribuye al sur de los 14°S. En ambos casos se observó que esta migración hacia el sur estuvo asociada con la propagación de las aguas calientes que fue mucho más acentuada durante los dos picos del Niño 1972-73.

En 1978, la distribución se restituye a toda la costa, con agregaciones notorias localizadas en los 14-15°S en el otoño-invierno y en los 8-9°S en la primavera; esta última extendiéndose hasta el verano 1979, coincidente con la normalización de las condiciones ambientales en dicho período.

A partir de 1979, es evidente la disminución de las áreas de distribución, remarcándose aún más esta situación durante el actual Niño 1982-83, en que la presencia de esta especie es casi nula en la capa superficial muestreada, como producto de la profundización del reducido stock hacia capas más profundas, ante un ambiente extremadamente inapropiado en superficie.

Cabe mencionar que en los años 1979-81 los datos del ambiente no muestran anormalidades significativas, por lo que podemos inferir que la disminución de las áreas de distribución se debe a la acción de la pesquería y a las interacciones intra e interespecíficas.

Más adelante y mediante el empleo de datos acústicos, se cuantifica esta reducción del área y se muestran índices de concentración, relacionando la abundancia con las áreas de distribución.

Sardina. En cuanto a la sardina (Fig. 28b) el incremento en las áreas de distribución es particularmente notorio a partir de 1977 y más aún, desde 1980 en que las mayores agregaciones se localizan al norte de los 11°S, principalmente entre los 6-8°S. Dichas áreas de mayor agregación no son coincidentes con aquellas mostradas para la anchoveta; observamos más bien, un nivel de coincidencia entre la distribución más septentrional de estas agregaciones de sardina, con la extensión hacia el norte de las aguas subtropicales invernales, con salinidades de 35.1-35.2°/oo.

Durante los Niños de 1972 y 1976, la distribución abarca mayor extensión que la observada para anchoveta, no mostrándose el desplazamiento hacia el sur descrito para la anchoveta; en cambio durante el actual Niño 1982-83 en que los calentamientos son más elevados, se puede apreciar que esta migración viene ocurriendo en la sardina. A este respecto cabe mencionar el reporte de marcas de sardina liberadas en el norte y centro de Perú, recuperadas en el litoral chileno en los meses de septiembre y diciembre de 1982 y febrero y marzo de 1983 (L. Gonzáles, comunicación personal). Asimismo, se han reportado altas capturas de sardina en el litoral norte de Chile, durante dicho período (ERFEN, 1983), lo que no es usual para la época.

A juzgar por la tendencia de las isolíneas podemos inferir que en cierta medida el desplazamiento de la sardina hacia el sur viene ocurriendo desde principios de 1982, coincidiendo con el calentamiento progresivo a partir del otoño 1982 (salinidades de 35.0-35.2°/oo), asociado con el Niño 1982-83 cuyo desarrollo desconcertó a la comunidad científica.

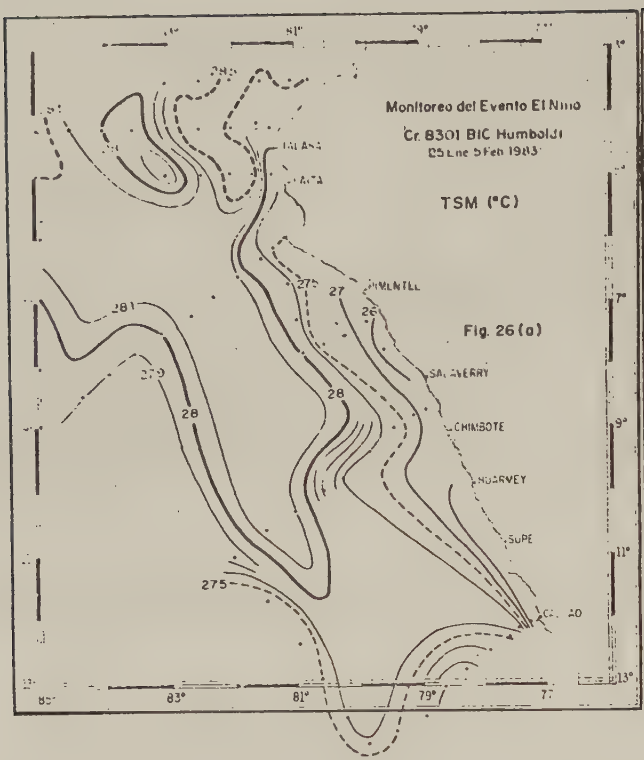

Monitoreo del Evento El Niño
Cr. 8301 BIC Humboldt
25 Ene 5 Feb 1983
TSM (°C)
TALARA
PAITA
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
CALLAO
28.1
27.9
28
27.5
27
26
275
81°
79°
77°
83°
85°
7°
9°
11°
13°

Fig. 26 (a)

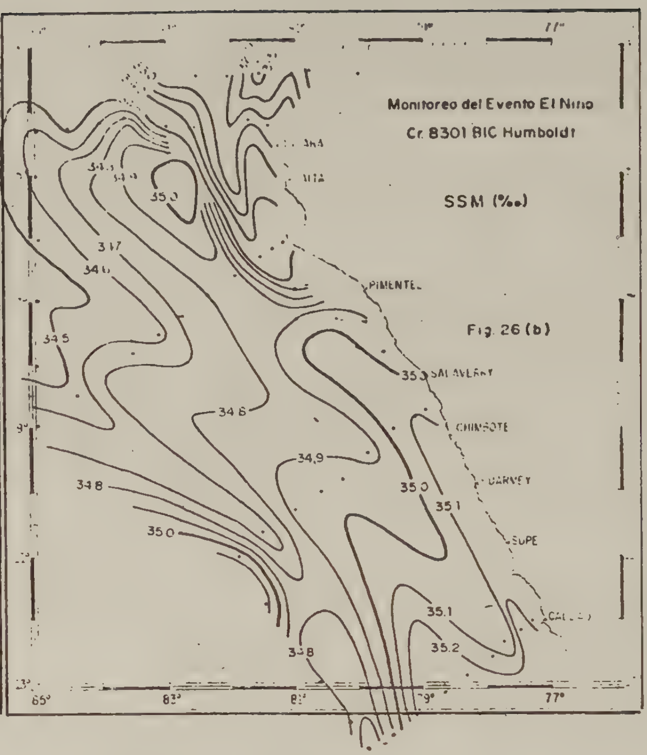

Monitoreo del Evento El Niño
Cr. 8301 BIC Humboldt
SSM (‰)
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
CALLAO
35.0
34.7
34.6
34.5
34.8
34.9
35.3
35.1
35.2
85°
83°
81°
79°
77°
9°
11°
13°

Fig. 26 (b)

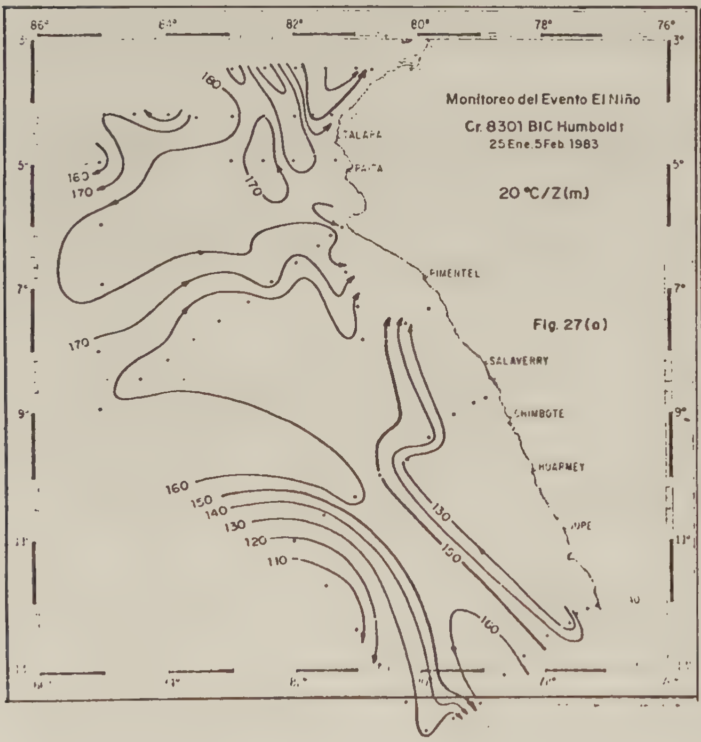

Monitoreo del Evento El Niño
Cr. 8301 BIC Humboldt
25 Ene.5 Feb 1983
20 °C / Z (m)
TALARA
PAITA
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
180
170
160
150
140
130
120
110
86°
84°
82°
80°
78°
76°
3°
5°
7°
9°
11°

Fig. 27 (a)

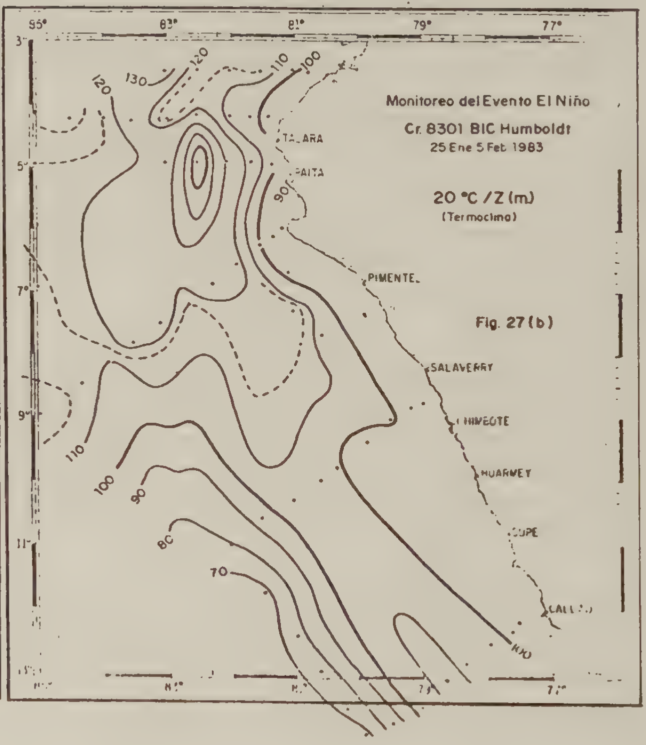

Monitoreo del Evento El Niño
Cr. 8301 BIC Humboldt
25 Ene 5 Feb 1983
20 °C / Z (m)
(Termoclino)
TALARA
PAITA
PIMENTEL
SALAVERRY
CHIMBOTE
HUARMEY
SUPE
CALLAO
130
120
110
100
90
80
70
85°
83°
81°
79°
77°
3°
5°
7°
9°
11°

Fig. 27 (b)

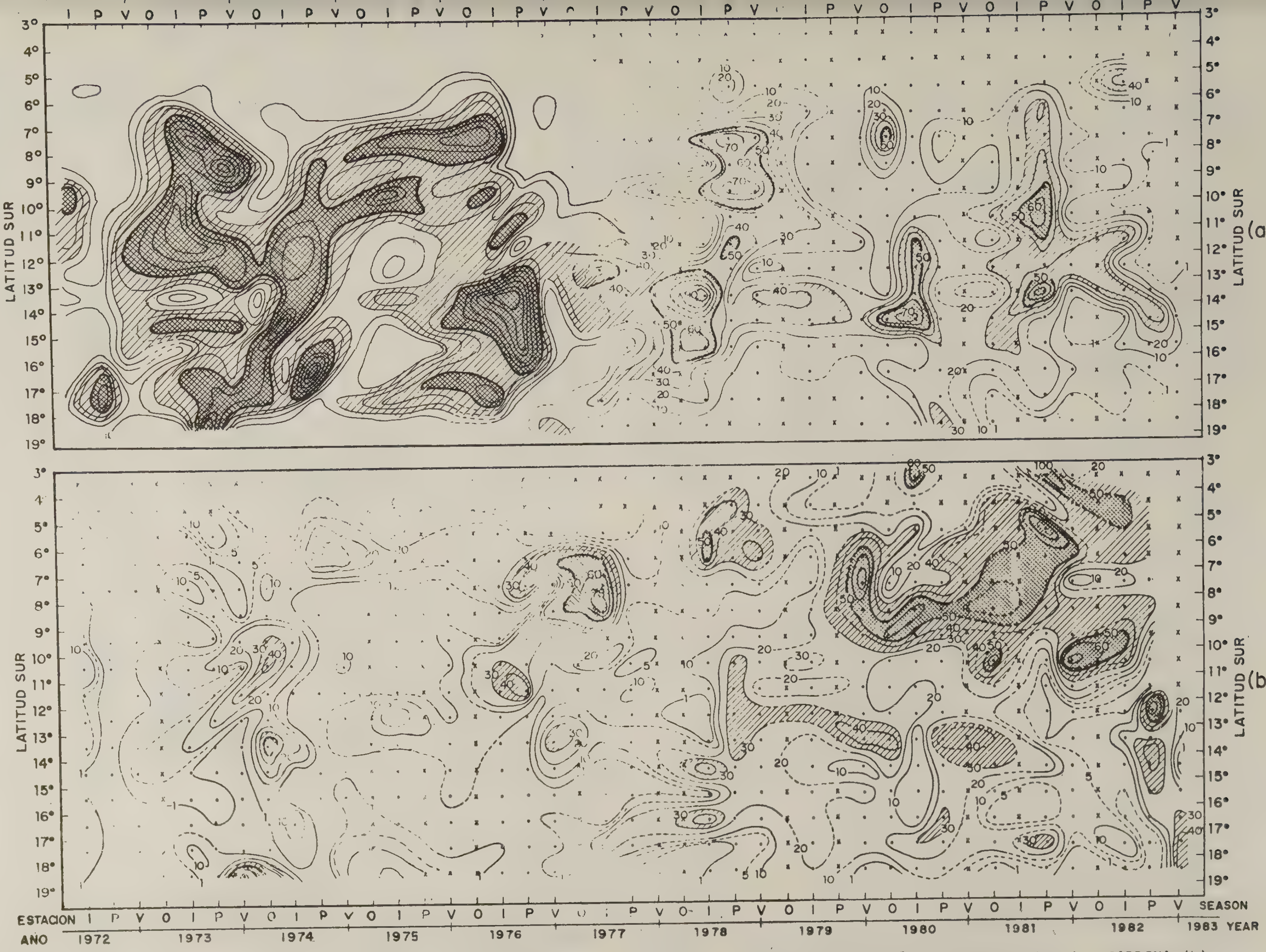


Fig. 28. Variaciones estacionales e interanuales en la distribución e "Indices de agregación" de ANCHOVETA (a) y SARDINA (b), frente a la costa peruana. Invierno 1972.Verano 1983. Seasonal and annual variations in the distribution and "Aggregation index" of ANCHOVETA (a) and SARDINA (b), along the Peruvian coast. Winter 1972-Summer 1983. x Sin datos. Without data. ▩ Más de 20% de la captura en peso. More than 20% of the catch in weight. ▨ Entre 5-20% de la captura en peso. 5-20% of the catch in weight.

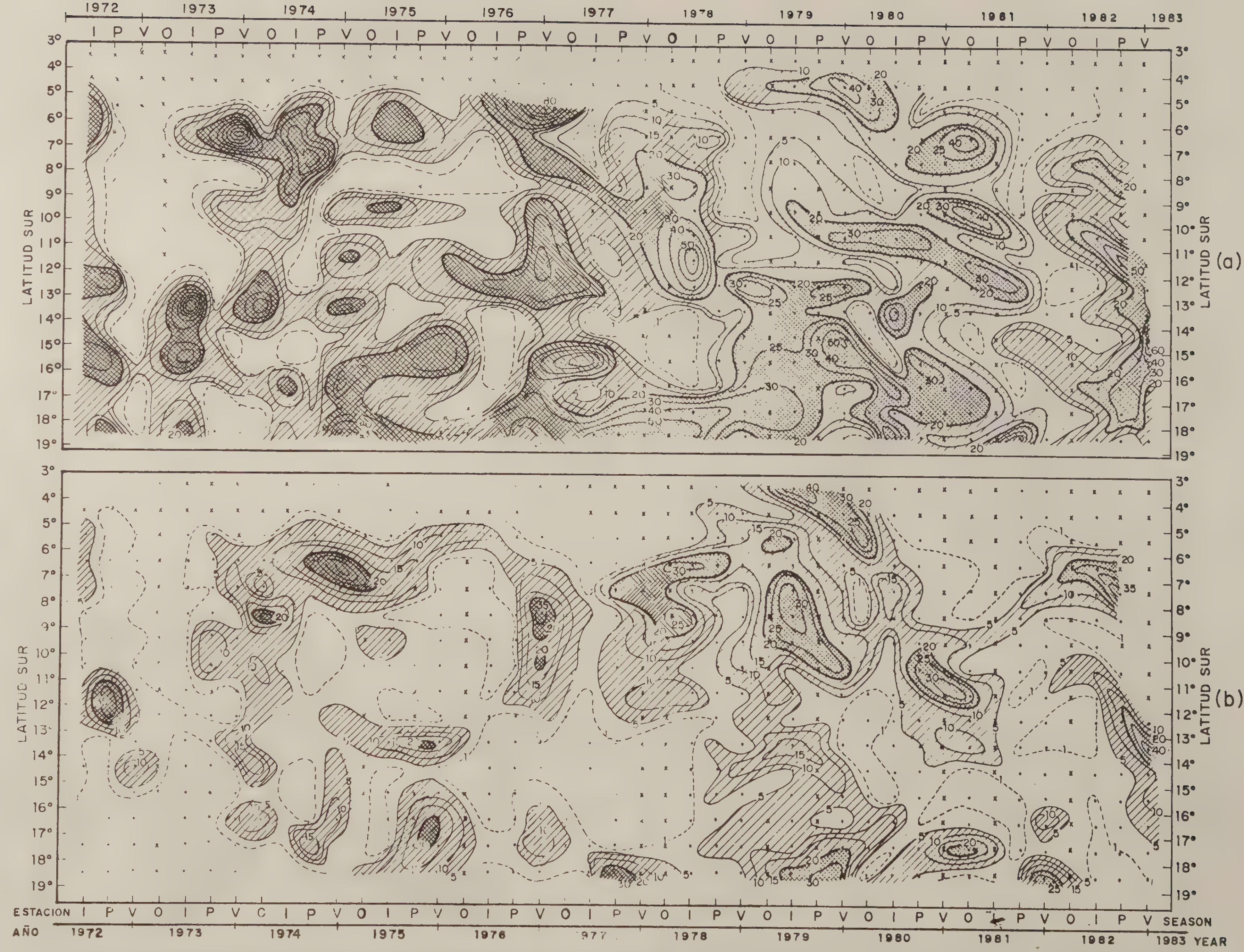


Fig. 29. Variaciones estacionales e interanuales en la distribución e "Indices de agregación" de JUREL (a) y CABALLA (b), frente a la costa peruana. Invierno 1972-Verano 1983. Seasonal and annual variations in the distribution and "Aggregation index" of JUREL (a) and CABALLA (b), along the peruvian coast. Winter 1972-Summer 1983. x Sin datos. Without data. ▩ Más de 20% de la captura en peso. More than 20% of the catch in weight. ▨ Entre 5-20% de la captura en peso. Between 5-20% of the catch in weight.

Jurel. El jurel (Fig. 29a), al igual que la sardina, ha expandido su área de distribución con agregaciones apreciables a lo largo de la costa peruana, particularmente después del Niño 1976. Durante los Niños de 1972 y 1976, las áreas de distribución así como los focos de agregación de jurel fueron más amplios que los observados para sardina; durante El Niño 1982-83 la tendencia de las ilolíneas de alta agregación sugieren que en cierta medida aunque poco perceptible se está produciendo también desplazamientos hacia el sur de la costa peruana y norte de Chile.

La proyección hacia el sur de las áreas de alta agregación en todo el período presentado indican claramente que en el norte de Chile las agregaciones también son apreciables y que se reflejan en las altas capturas de esta especie por la pesquería del norte de Chile en los últimos años.

No obstante que el jurel muestra una amplia distribución a lo largo de toda la costa peruana, se aprecia una mayor permanencia de las grandes áreas de alta agregación, al sur de los 10°S. El cuadro presentado sugiere que esta especie tiene un mayor grado de adaptación a las variaciones del ambiente, como se discutirá posteriormente.

Caballa. En la caballa (Fig. 29b) también se aprecia una ampliación de las áreas de distribución particularmente después del Niño 1976, localizándose las mayores agregaciones al norte de los 11°S, contrariamente a lo observado para el jurel. Entre los 14-15°S las agregaciones altas son poco perceptibles para incrementarse luego al sur de los 17°S así como para el jurel, aunque en menor extensión.

La creciente expansión de las áreas de distribución de jurel y caballa hasta muy cerca de la costa peruana, se ha visto reflejada en los aumentos de las capturas de la flota artesanal cuya actividad es continuada y donde el número de barcos no ha sufrido grandes incrementos como el de otras flotas; por lo tanto, el incremento de las capturas de estas especies por la flota artesanal indicaría también la expansión en la distribución de jurel y caballa en los últimos años.

Cambios en la extensión de las áreas y en el grado de concentración del stock de anchoveta. Los cambios en la extensión de las áreas de distribución de anchoveta para el período 1966-1973 fueron presentados por IMARPE (1973) en base a datos acústicos, considerando las áreas con densidades relativas correspondientes a las categorías disperso, denso y muy denso (escalas 2, 3 y 4). En los análisis que se presentan en esta sección se incluye además la categoría muy disperso (escala 1). Se abarca el período 1966-79, lo cual ha permitido (empleando datos diferentes a los usados en la Fig. 28a), cuantificar la magnitud en la reducción de las áreas de distribución de anchoveta en este período.

El patrón típico de la distribución mar afuera de la anchoveta en la década de los años 60 se caracterizó por ser más amplia en el invierno hasta aproximadamente 100-120 millas al oeste, conformado mayormente por cardúmenes dispersos y muy dispersos; mientras que en el verano fue más costera distribuyéndose hasta aproximadamente 40-50 millas, con predominancia de agregaciones densas y muy densas. Este patrón estuvo condicionado por las características ambientales estacionales descritas en las secciones anteriores y el alto nivel poblacional que exhibió la población de esos años.

Sin embargo, la declinación del stock de anchoveta en los últimos años es de tal magnitud (Johannesson y Vílchez, 1981), que el patrón considerado como característico para el invierno y verano bajo situaciones "normales" se oscurece.

Este hecho se visualiza en las Figs. 30 (a, b) y 31 y Tabla 1, donde se muestra que a partir de 1972 la extensión de las áreas con anchoveta no exhibe las fluctuaciones para el invierno y verano que fue notorio en los años anteriores. También es evidente la disminución del área ocupada por la anchoveta en los años 1972-79 que, comparada con el período 1966-71, representa alrededor del 50%.

De otro lado, Johannesson y Vílchez (1980) muestran que se han producido violentas oscilaciones en la densidad promedio del stock de anchoveta en el período 1973-79 y que los incrementos en la densidad pueden coincidir ya sea con un incremento o con una disminución en la extensión del área.

Basados en este hecho, los incrementos en densidad asociados con la disminución del área indicarán el mayor grado de concentración en que se encuentra el stock.

**Tabla 1** Cambios en la extensión de las áreas de distribución y concentración de anchoveta, 1966-79.

Changes in the extent of the anchoveta distribution area and concentration, during 1966-79.

| PROSPECCION<br>Survey | FECHA<br>Date | ESTACION<br>Season | AREA CON ANCHOVETA Area with anchoveta (mn$^2$) | GRADOS DE LATITUD CUBIERTAS Latitud degrees coverage | AREA/GRADO LAT. Area/Lat.degree | INDICE DE ABUNDANCIA ACUSTICA Acoustic abundance index | AREA, CATEG. 2-4 Area, categ. 2-4 (mn$^2$) | INDICE DE CONCENTRACION Concentration index |
|---|---|---|---|---|---|---|---|---|
| Eureka IV | Agosto 1966 | Invierno | 14770 | 6 | 2462 | 725 | 1108 | 0.6 |
| Eureka VIII | Agosto 1967 | Invierno | 21515 | 10 | 2152 | 724 | 1116 | 0.6 |
| Eureka IX | Marzo 1968 | Verano | 31360 | 9 | 3484 | 607 | 1464 | 0.4 |
| Eureka X | Agosto 1968 | Invierno | 27380 | 8 | 3422 | 806 | 2198 | 0.6 |
| Cr. 6902-03 | Febrero 1969 | Verano | 8627 | 8.5 | 1015 | 1192 | 651 | 1.8 |
| Eureka XIV | Setiembre 1969 | Invierno | 31280 | 10 | 3128 | 582 | 1362 | 0.4 |
| Eureka XV | Marzo 1970 | Verano | 12785 | 6.5 | 1967 | 868 | 1082 | 0.8 |
| Eureka XVII | Agosto 1970 | Invierno | 14923 | 10 | 1492 | 849 | 530 | 1.6 |
| Eureka XVIII | Febrero 1971 | Verano | 30100 | 10.5 | 2867 | 711 | 1735 | 0.4 |
| Eureka XIX | Agosto 1971 | Invierno | 44268 | 9 | 4919 | 698 | 2298 | 0.3 |
| OYSCA 7202 | Febrero 1972 | Verano | 11070 | 8 | 1334 | 1042 | 322 | 3.2 |
| Eureka XXIV | Setiembre 1972 | Invierno | 16525 | 13.5 | 1224 | - | - | - |
| Eureka XXVI | Enero 1973 | Verano | 14231 | 13.5 | 1054 | 917 | 373 | 2.5 |
| Cr. 7302 | Febrero 1973 | Verano | 5876 | 10 | 588 | 1350 | 382 | 3.5 |
| Eureka XXVII | Setiembre 1973 | Invierno | 28412 | 12.5 | 2273 | 430 | 217 | 2.0 |
| Cateo 4 | Febrero 1974 | Verano | 26869 | 12.5 | 2150 | 563 | 279 | 2.0 |
| Eureka XXX | Agosto 1974 | Invierno | 27325 | 12.5 | 2186 | 501 | 515 | 1.0 |
| Eureka XXXI | Setiembre 1974 | Invierno | 18510 | 12.5 | 1481 | 667 | 600 | 1.1 |
| Eureka XXXII | Febrero 1975 | Verano | 20316 | 12.5 | 1625 | 681 | 585 | 1.1 |
| Eureka XXXIII | Agosto 1975 | Invierno | 20165 | 13.5 | 1493 | 624 | 382 | 1.6 |
| Eureka XXXV | Enero 1976 | Verano | 23899 | 13.5 | 1770 | 833 | 643 | 1.3 |
| Cr. 7603 | Marzo 1976 | Verano | 19345 | 13.5 | 1433 | 1759 | 346 | 5.1 |
| Eureka XXXVI | Agosto 1976 | Invierno | 25216 | 13.5 | 1868 | 630 | 527 | 1.2 |
| Cr. 7609 | Setiembre 1976 | Invierno | 14320 | 12.5 | 1138 | - | - | - |
| Cr. 7703 | Marzo 1977 | Verano | 6690 | 12.5 | 535 | 1506 | 256 | 2.9 |
| Cr. 7903 | Marzo 1979 | Verano | 12640 | 12.5 | 1011 | - | - | - |

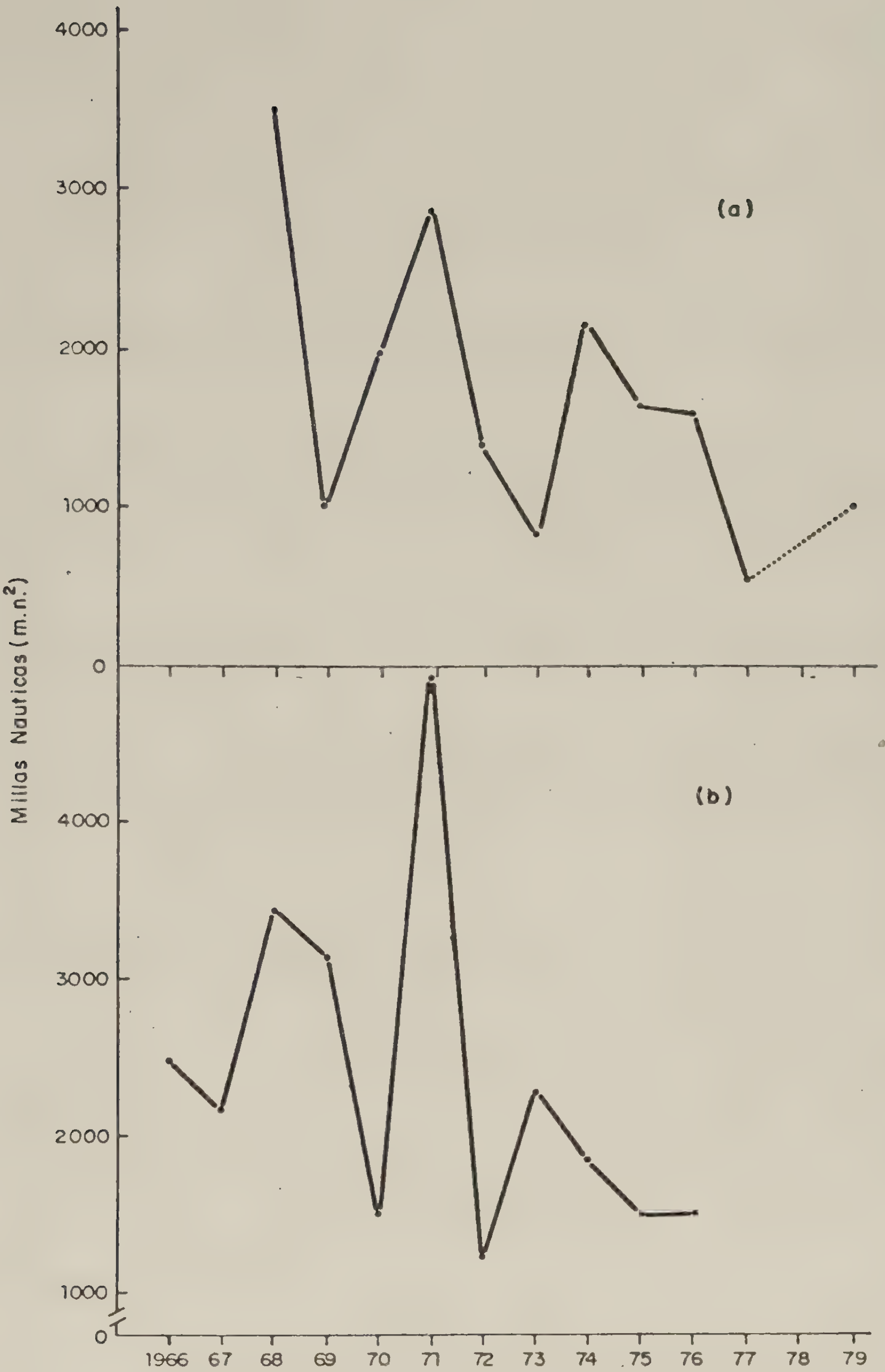


Fig. 30 Cambios en la extension del area habitada por la Anchoveta, 1966-79: (a) Verano, (b) Invierno (m.n.$^2$ promedio por grados de latitud).

Fig. 30 Changes in the extent of area inhabitated by Anchoveta, 1966 - 79 (a) Summer, (b) Winter (average by latitude degree).

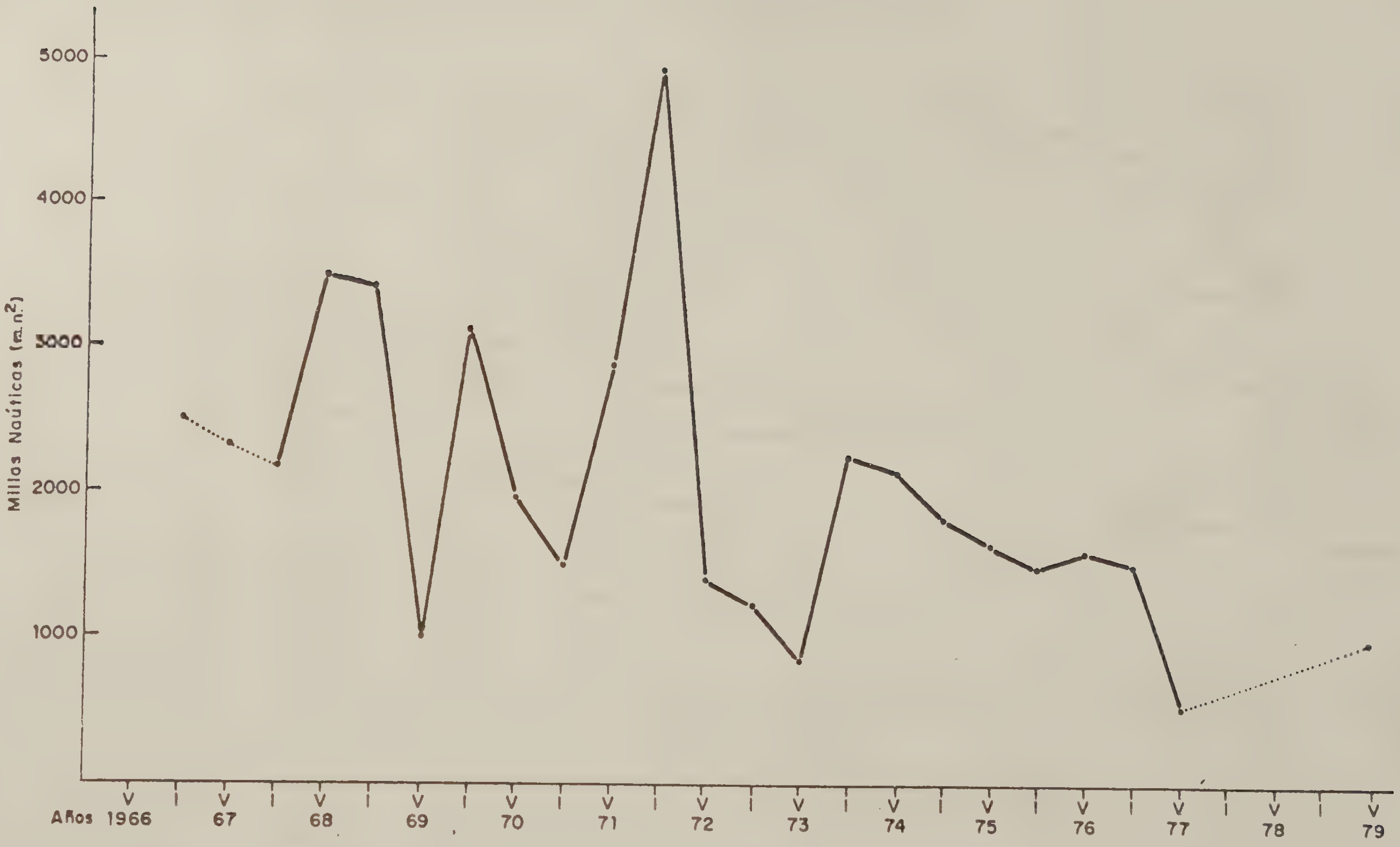


Fig. 31 Cambios en la extensión del área habitada por la Anchoveta, 1966-1979. (m.n.$^2$ promedio por grados de latitud )
Changes in the extent of the area inhabitated by Anchoveta, 1966-79 (average by latitude degree).

Para calcular el índice de concentración se han empleado los datos de abundancia de las prospecciones Eureka considerando las categorías disperso, denso y muy denso (categorías 2-4) que según Johannesson y Robles (1977) corresponden a densidades de 430, 1550 y 5300 TM/mn$^2$ para las categorías mencionadas, respectivamente, relacionándolas con la extensión de dichas áreas, tal como se muestra en la Fig. 32 y Tabla 1. Los puntos graficados en la parte superior izquierda indican por lo tanto, los meses de máxima concentración y que corresponden a períodos con calentamientos apreciables; en contraste, los puntos situados en la parte inferior derecha indican los meses de mínima concentración de cardúmenes de anchoveta, que corresponden a los meses fríos y normales. En la Fig. 33 se han graficado los valores de estos índices de concentración en secuencia de tiempo.

Johannesson y Vílchez (1981) empleando datos de ecointegración indican que en el crucero de febrero 1973, el 55% de la biomasa estuvo concentrada en sólo 13% del área total de distribución y en el crucero de marzo 1976, el 36% de la biomasa se concentró en sólo 3.4% del área total.

Los índices altos de concentración generan un incremento en la densidad total, produciendo una mayor interacción entre las mismas anchovetas y entre la anchoveta y sardina que comparten el mismo habitat, creando un estado de tensión que a su turno conducen a una declinación del potencial reproductivo, activando a su vez un conjunto de reacciones corporales.

Las implicancias de este fenómeno así como los posibles efectos dependientes de la densidad, han sido discutidas por Csirke (1980), Sharp (1981), MacCall (1981), Tsukayama y Alvares (1981), Ware y Tsukayama (1981).

La dramática reducción en el peso corporal de las anchovetas adultas registrada en El Niño de 1982-83 (Fig. 34), en un 27% con respecto al período 1961-64, cuando la magnitud de la población era alta y las condiciones ambientales estables, evidencia una vez más el estado de intenso stress en que se encuentra el stock, por efecto de factores tanto intrínsecos como extrínsecos.

En Niños anteriores se observó también reducción en el peso, como una respuesta a un ambiente inapropiado, que fueron de 22% en marzo de 1976, 15% en octubre del mismo año y 11% en abril de 1977, atribuíbles a una insuficiente cantidad de alimento disponible, bajo situaciones de altas concentraciones del stock (IMARPE 1977).

Otra reacción observada, es la referente a los altos contenidos grasos que exhibieron las anchovetas, meses antes del desarrollo pleno de los Niños 1972-73 y 1982-83, aún cuando bajo circunstancias diferentes. Previo el Niño 1972-73 (agosto y setiembre 1981) el alto contenido de grasa estuvo relacionado con una actividad reproductiva reducida (IMARPE, 1972), mientras que previo al Niño 1982-83 (febrero-marzo 1982) la actividad reproductiva era apreciable (IMARPE, 1982). Los mecanismos fisiológicos de este proceso no están totalmente esclarecidos, pero estas observaciones pueden interpretarse como una reacción anticipada del stock frente a condiciones desfavorables del ambiente.

## Cambios en la Composición por Especies

En la década de los años 1950 y 1960 y hasta antes de la ocurrencia del Niño 1972, la anchoveta fue el recurso pesquero nerítico pelágico dominante del gran complejo de la corriente peruana. Esto es evidente del análisis de las descargas de la pesca comercial que operó con redes de cerco (boliche), donde la proporción de esta especie constituyó más del 95% del total capturado de especies pelágicas en la costa peruana. Los análisis de restos de peces en los sedimentos marinos sugieren también una dominancia histórica de la anchoveta en la comunidad de peces pelágicos frente al Perú (De Vries y Pearcy, 1982).

Es a partir de 1972 cuando se aprecia tanto en las capturas comerciales, así como en las prospecciones efectuadas por IMARPE, una disminución en la proporción de anchoveta y un paulatino incremento de las otras especies pelágicas, constituyendo capturas mixtas.

Como se ha mostrado también en las Figs. 28 y 29 y a fin de cuantificar estos cambios en la composición por especies, se han usado datos de las prospecciones científicas, los cuales han sido agrupados tanto a nivel Perú como por zonas (Figs. 35, 36, 37, 38 y 39). En todas las zonas es notoria la disminución en la proporción de anchoveta y un incremento en la sardina; para el jurel y la caballa este incremento también se da, aunque es menos conspicuo, en parte debido a los aparejos de pesca usados en estas prospecciones.

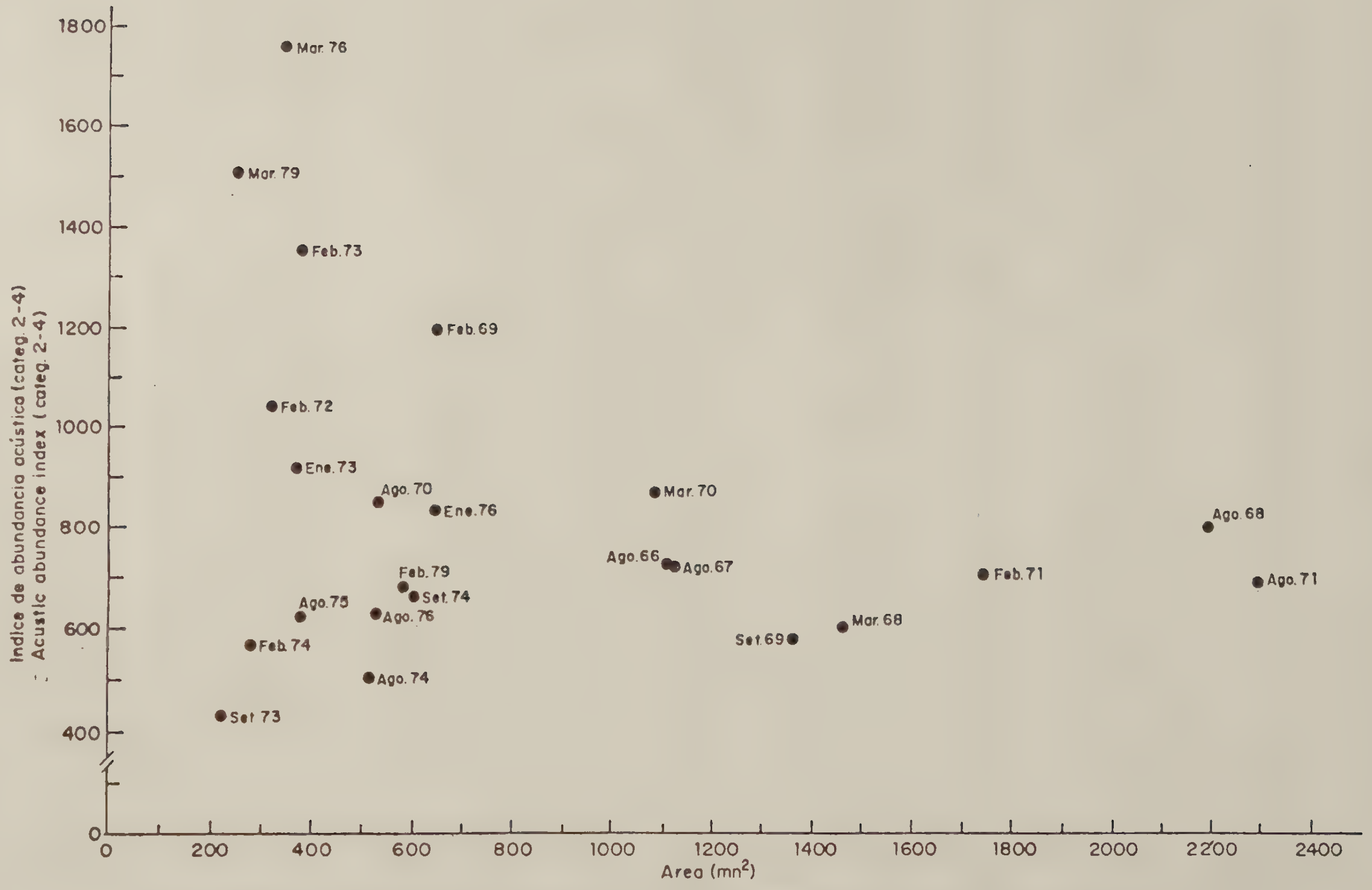


Fig. 32 Relación entre la abundancia y extensión de las áreas, con cardúmenes dispersos, densos y muy densos (categ. 2-4)
Relationship between anchoveta abundance and area extent inhabitated by disperse, dense and very dense shoals (categ. 2-4)

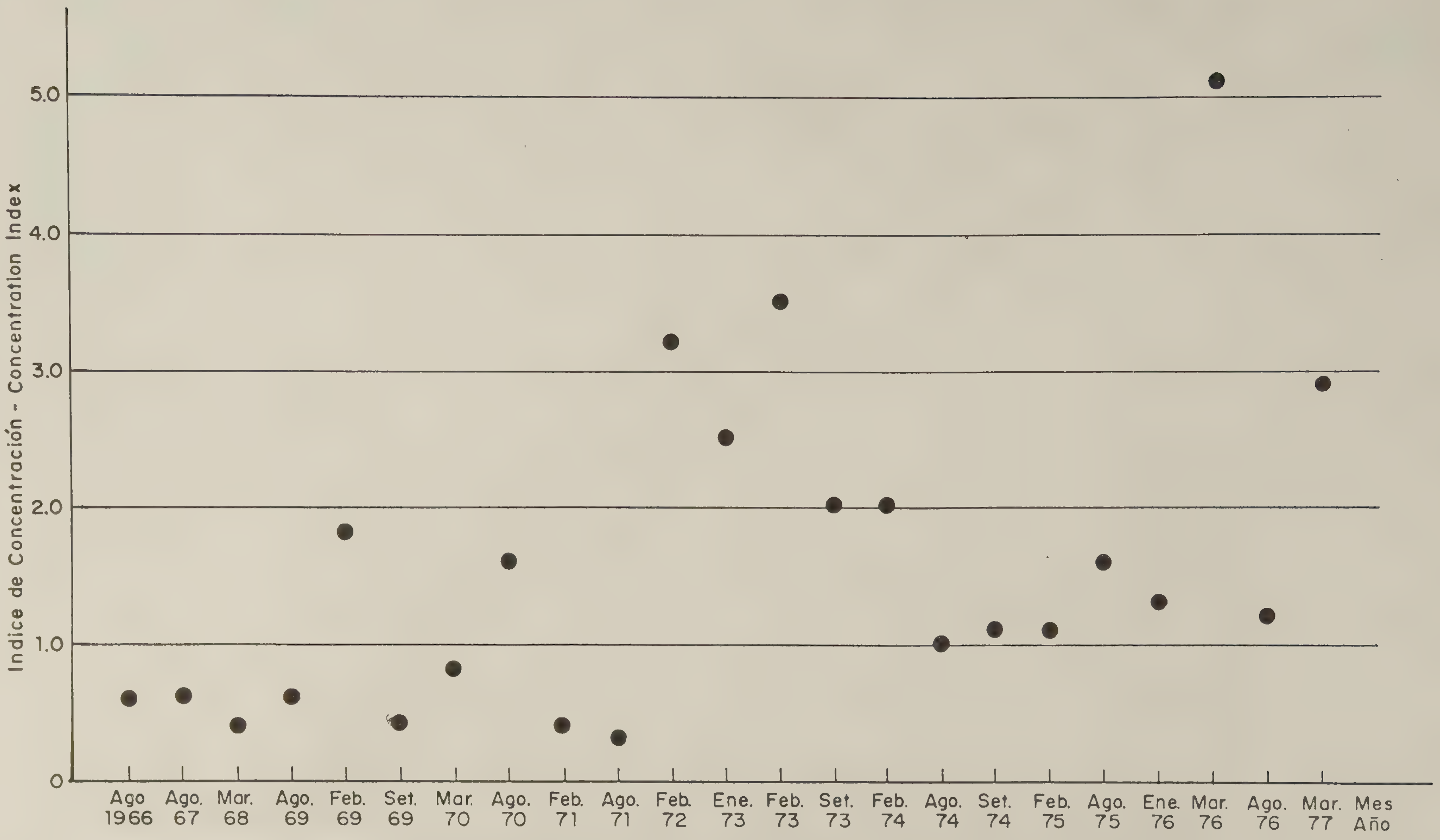


Fig. 33 Variaciones en el indice de concentración del stock de Anchoveta durante los años 1966-1977.
Changes in the concentration index of the Anchoveta stock during 1966-1977.

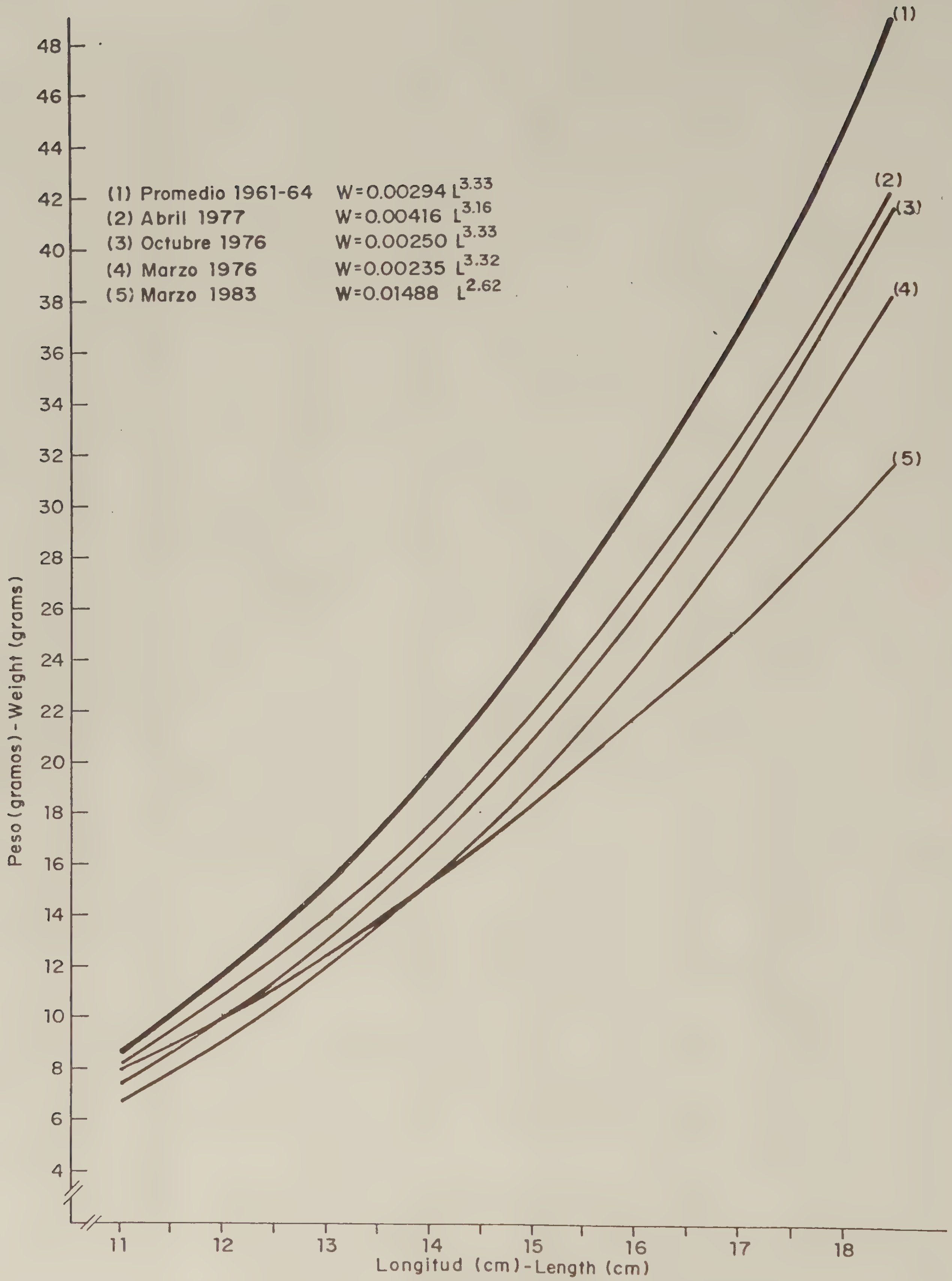


Fig. 34 Variaciones en la relación longitud-peso de Anchoveta.
Variations in the Anchoveta length-weight relationship.

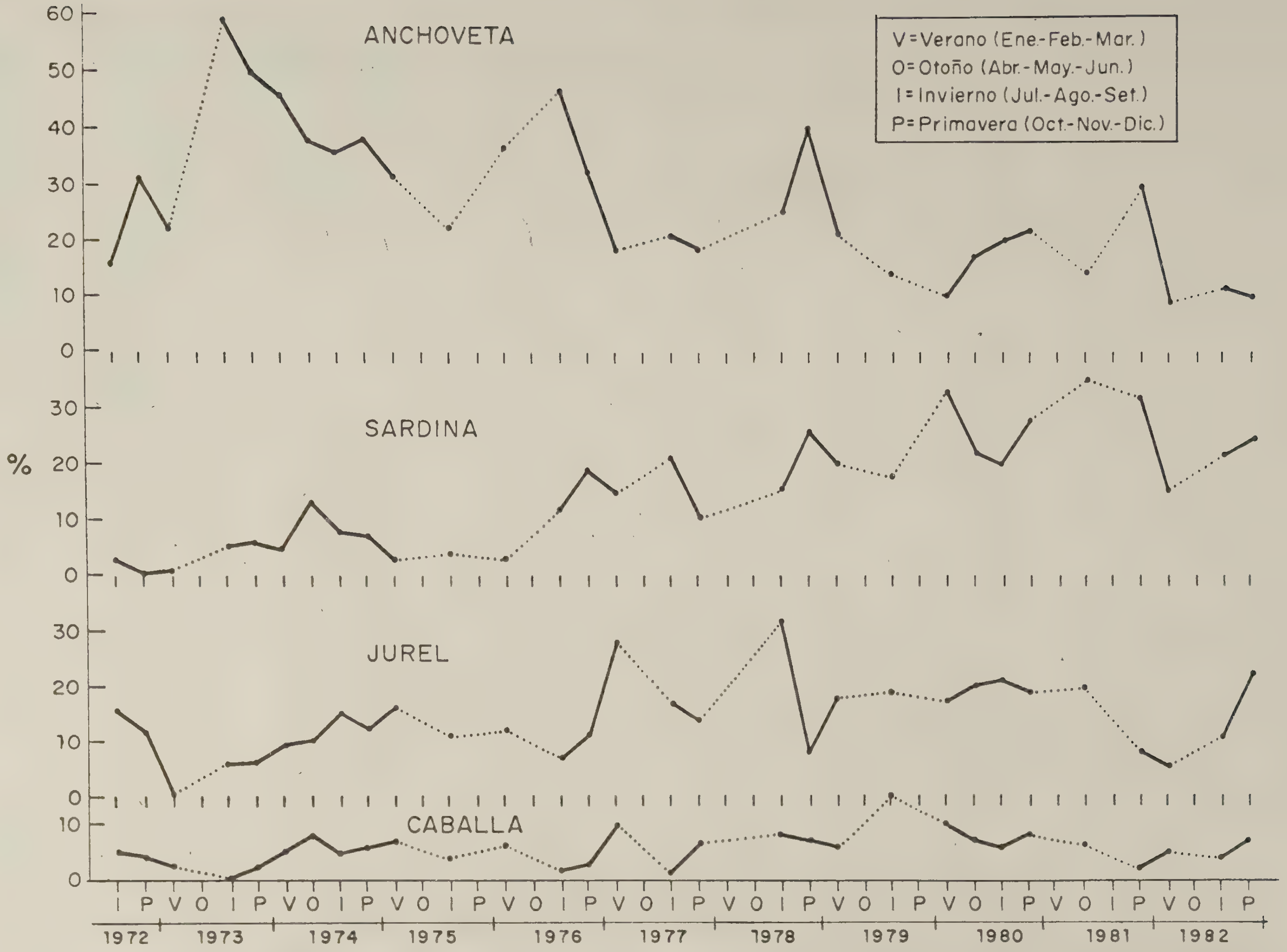


Fig. 35 Composición por especies pelágicas (%) por estaciones y años, en la costa peruana. (Datos de calas de cruceros acústico-pesqueros y eurekas.)

Pelagic species composition (%) along peruvian coast by seasons and years. (Data from hauls made during Eurekas and Cruises.)

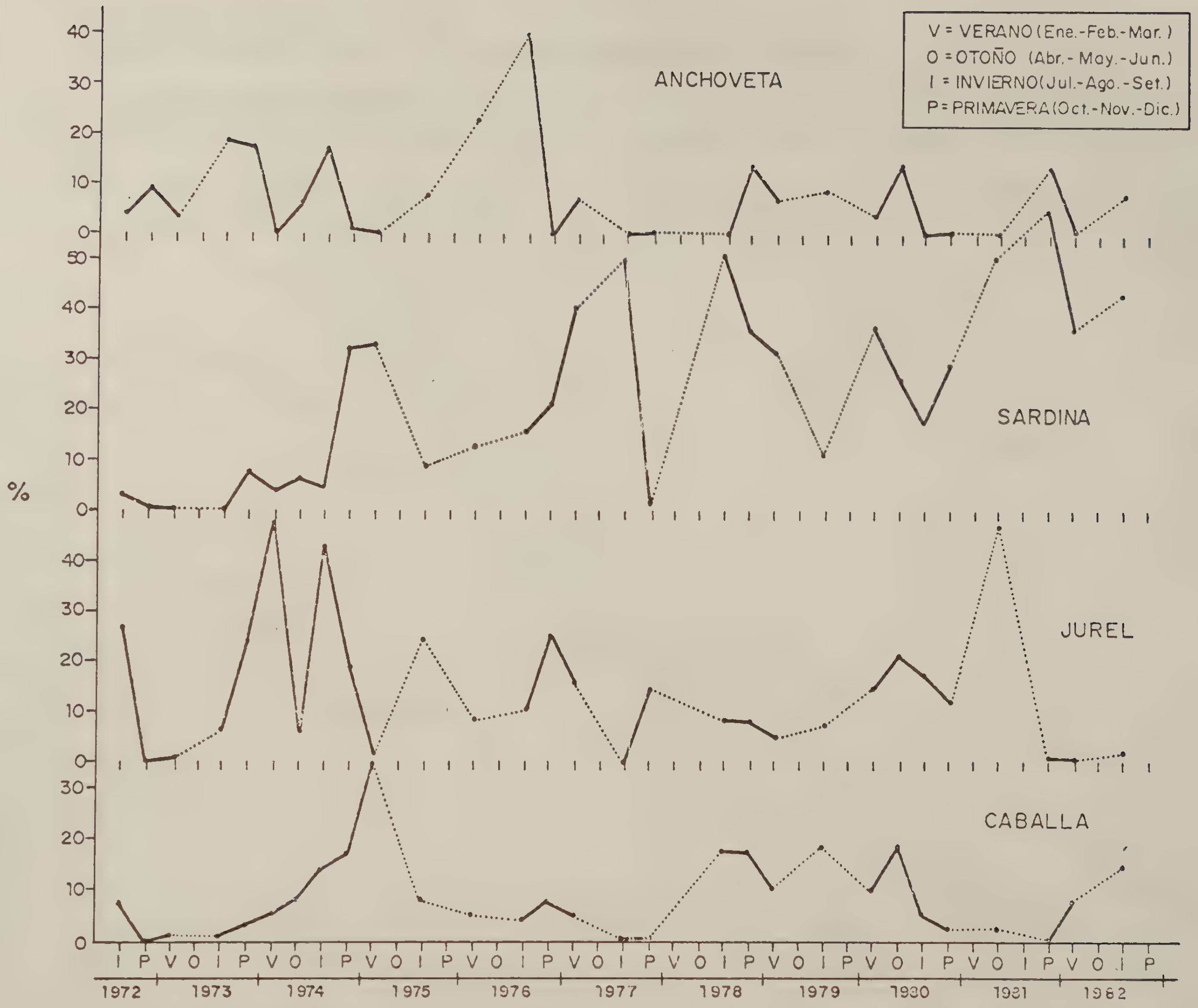


Fig. 36 Composición por especies pelagicas (%) por estaciones y años, en la zona comprendida entre 3° y 7° S: Frontera Norte a Pimentel. (Datos de calas de cruceros acústico-pesqueros y eurekas).
Pelagic species composition (%) by seasons and years at 3°-7°S: Frontera Norte-Pimentel. (Data from hauls made during Eurekas and Cruises.)

El cerco anchovetero empleado, proporciona informaciones más representativas de la anchoveta y sardina que habitan fundamentalmente en las capas superficiales, formando agregaciones densas y altamente vulnerables a estas redes, mientras que el jurel y la caballa se encuentran también en capas más profundas y conformando cardúmenes más dispersos y en consecuencia, menos vulnerables a dichas redes.

En la Tabla 2, se puede apreciar que la disminución en la proporción de anchoveta fue más drástica en el área de Pimentel-Huarmey (7-10°S) en los años 1972-77, con un valor de 29%, siendo de 43% y 31% para las áreas de Huarmey-Pisco (10-14°S) y Pisco-Frontera sur (14-19°S), respectivamente. En el período 1978-82 continúa el descenso en la proporción de anchovetas con valores de 26%, 27% y 16% para las tres áreas mencionadas, respectivamente. Cabe mencionar que el área más norteña de la costa peruana, tradicionalmente no ha sido productiva una zona de reproducción de anchoveta por las características ambientales que imperan en esa región. Las zonas comprendidas entre los 6-14°S (Paita-Pisco), características por las de la plataforma continental y los intensos y permanentes afloramientos son los que propiciaron que una altísima producción de esta especie, como se detalla en las secciones anteriores.

El incremento de la proporción de sardina es notoria en todas las zonas y aún cuando ya se aprecia desde 1972, es más conspicua en el período 1978-1982. La sardina antes del Niño 1972 ocupó principalmente el área septentrional de la costa peruana, aunque en proporciones muy reducidas, por esta razón dicha área se constituyó en la base de las actividades de la flota artesanal y conservera, cuyo radio de acción comprendió los puertos de Paita, Chicama y Chimbote.

A nivel de toda la costa, la proporción de anchoveta ha disminuido del 32% en el período 1972-77 al 20% en los años 1978-82; en estos mismos períodos la sardina, jurel y caballa se incrementaron de 6 a 23%, de 11 al 16% y del 5 al 8%, respectivamente.

Los cambios en la proporción de especies que aquí se presentan, guardan correspondencia con las informaciones dadas por Santander (1981) quien indica que en el período 1961-71 los huevos y larvas de anchoveta dominaron en el ictioplancton con una proporción que varió entre el 65-90%; en 1972-73 disminuye al 47-50%, y desde 1974 a 1980 la proporción ha variado notablemente, registrándose sólo un 20% de huevos de anchoveta en septiembre de 1979.

## Cambios en la Abundancia de las Poblaciones Pelágicas

Con respecto a la anchoveta: Los estimados de biomasa de anchoveta efectuados por IMARPE a lo largo de la costa peruana en el período 1963-81, fueron sumarizados por Tsukayama (1983, en prensa), donde se aprecia que esta población ha sufrido grandes fluctuaciones en el período en mención, con un máximo de 22 millones de toneladas métricas en 1967 y mínimos de 2-3 millones de toneladas en los últimos años (Fig. 40).

La declinación más drástica ocurrió en 1972 coincidente con el Niño de ese año, en que de 15.0 millones de toneladas que se tuvo como promedio en los años previos de 1970-71, desciende hasta 9.0 millones de toneladas a comienzos de 1972 y a 4.1 a fines del mismo año. En los años 1973-75 la biomasa promedio es de 5.6 millones de toneladas; a comienzos de 1976 se incrementó a 10.6 millones de toneladas y a fines de 1976 y comienzos de 1977 con la ocurrencia nuevamente de transtornos en el ambiente, la población disminuye aún más, hasta alrededor de 3.0 millones de toneladas; en 1978-81 la biomasa promedio es de 2.7 millones de toneladas.

A fin de explicar esta dramática reducción del stock de anchoveta e inferir en qué medida ello se ha producido como consecuencia de la presión de la pesquería de los cambios en el ambiente durante este período, Tsukayama (1983, en prensa) estimó tasas de explotación calculadas de la proporción entre las capturas (en peso) y las biomasas. Los valores promedios obtenidos fueron de 0.47 para los años 1963-66, 0.55 en los años 1967-69 y 0.77 en los años 1970-71 (Tabla 3).

Esta altísima tasa de explotación en los años inmediatamente antes del Niño 1972, operó fundamentalmente sobre las anchovetas más pequeñas que se hacían altamente vulnerables a la pesca durante los meses de verano que corresponden al período de reclutamiento. Los datos presentados por IMARPE (1972) y que se refieren al seguimiento de las clases

Tabla 2 Cambios en la composición por especies pelágicas (%) por zonas, estaciones y años, durante Invierno 1972 - Verano 1983.
Changes in the pelagic species composition (%) by zones, seasons and years during Winter 1972 - Summer 1983.

| ZONA | AÑOS | COMPOSICION POR ESPECIES (%) | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VERANO | | | | | OTOÑO | | | | | INVIERNO | | | | | PRIMAVERA | | | | | VER. + OTO. + INV. + PRIM. | | | | |
| | | Anch. | Sard. | Jur. | Cab. | Otros | Anch. | Sard. | Jur. | Cab. | Otros | Anch. | Sard. | Jur. | Cab. | Otros | Anch. | Sard. | Jur. | Cab. | Otros | Anch. | Sard. | Jur. | Cab. | Otros |
| Frontera Norte-Pimentel: 3-7°S | 1972 | - | - | - | - | - | - | - | - | - | - | 4 | 3 | 27 | 7 | 59 | 9 | 0 | 0.1 | 0 | 91 | 5 | 2 | 20 | 5 | 68 |
| | 1973 | 3 | 0 | 0.1 | 0.4 | 96 | - | - | - | - | - | 19 | 0.1 | 6 | 0.1 | 74.8 | 18 | 7 | 24 | 3 | 48 | 12 | 2 | 7 | 1 | 78 |
| | 1974 | 0 | 4 | 48 | 5 | 43 | 6 | 6 | 6 | 8 | 74 | 17 | 5 | 43 | 14 | 21 | 0.7 | 32 | 19 | 17 | 69 | 6 | 16 | 19 | 12 | 47 |
| | 1975 | 0 | 33 | 2 | 35 | 30 | - | - | - | - | - | 8 | 9 | 24 | 8 | 51 | - | - | - | - | - | 7 | 13 | 20 | 13 | 47 |
| | 1976 | 23 | 13 | 8 | 5 | 51 | - | - | - | - | - | 40 | 16 | 10 | 4 | 30 | 0 | 21 | 25 | 7 | 47 | 25 | 15 | 10 | 5 | 45 |
| | 1977 | 6 | 41 | 16 | 5 | 32 | - | - | - | - | - | 0 | 50 | 0 | 0 | 50 | 0 | 2 | 14 | 0 | 84 | 3 | 30 | 13 | 3 | 51 |
| | 1978 | - | - | - | - | - | - | - | - | - | - | 0 | 51 | 8 | 17 | 24 | 14 | 36 | 8 | 17 | 25 | 12 | 35 | 8 | 17 | 25 |
| | 1979 | 7 | 32 | 5 | 10 | 46 | - | - | - | - | - | 9 | 11 | 7 | 18 | 55 | - | - | - | - | - | 8 | 20 | 6 | 15 | 51 |
| | 1980 | 4 | 37 | 14 | 10 | 35 | 14 | 26 | 21 | 18 | 21 | 0 | 18 | 17 | 5 | 60 | 0.7 | 29 | 12 | 2 | 56 | 4 | 28 | 16 | 9 | 43 |
| | 1981 | - | - | - | - | - | 0 | 51 | 47 | 2 | 0 | - | - | - | - | - | 14 | 60 | 0.3 | 0.1 | 26 | 11 | 58 | 10 | 0.4 | 20 |
| | 1982 | 0.5 | 36 | 0.8 | 7 | 56 | - | - | - | - | - | 8 | 43 | 2 | 14 | 33 | - | - | - | - | - | 3 | 38 | 1 | 9 | 49 |
| | $\bar{X}$ 1972-77 | 10 | 12 | 7 | 4 | 68 | 6 | 6 | 6 | 8 | 74 | 14 | 6 | 19 | 5 | 56 | 7 | 14 | 16 | 7 | 56 | 11 | 10 | 14 | 5 | 60 |
| | $\bar{X}$ 1978-82 | 4 | 35 | 7 | 9 | 45 | 10 | 33 | 28 | 14 | 15 | 6 | 19 | 9 | 14 | 52 | 12 | 42 | 6 | 9 | 31 | 7 | 31 | 9 | 11 | 41 |
| Pimentel-Huarmey: 7-10°S | 1972 | - | - | - | - | - | - | - | - | - | - | 17 | 1 | 5 | 4 | 73 | 3 | 0 | 0 | 0 | 97 | 16 | 1 | 5 | 6 | 74 |
| | 1973 | 0.6 | 0.1 | 0.2 | 2 | 97 | - | - | - | - | - | 70 | 8 | 0.5 | 0.5 | 21 | 64 | 4 | 5 | 4 | 23 | 37 | 4 | 1 | 2 | 56 |
| | 1974 | 50 | 7 | 8 | 8 | 27 | 15 | 22 | 13 | 10 | 40 | 11 | 10 | 24 | 9 | 46 | 41 | 0 | 25 | 2 | 32 | 27 | 10 | 17 | 7 | 39 |
| | 1975 | 41 | 0.6 | 3 | 6 | 49 | - | - | - | - | - | 43 | 0.4 | 4 | 10 | 42 | - | - | - | - | - | 42 | 0.5 | 3 | 7 | 47 |
| | 1976 | 47 | 1 | 4 | 1 | 47 | - | - | - | - | - | 48 | 3 | 2 | 0.5 | 46 | 8 | 25 | 9 | 2 | 56 | 39 | 6 | 5 | 1 | 49 |
| | 1977 | 10 | 23 | 20 | 23 | 24 | - | - | - | - | - | 0 | 67 | 9 | 2 | 22 | 8 | 17 | 16 | 12 | 52 | 8 | 21 | 17 | 15 | 39 |
| | 1978 | - | - | - | - | - | - | - | - | - | - | 36 | 13 | 23 | 16 | 12 | 69 | 8 | 3 | 8 | 12 | 62 | 9 | 7 | 10 | 12 |
| | 1979 | 63 | 11 | 0.2 | 3 | 23 | - | - | - | - | - | 4 | 13 | 18 | 30 | 35 | - | - | - | - | - | 29 | 12 | 10 | 18 | 31 |
| | 1980 | 4 | 64 | 5 | 13 | 14 | 21 | 41 | 5 | 8 | 25 | 1 | 36 | 10 | 14 | 39 | 17 | 38 | 14 | 10 | 21 | 10 | 45 | 10 | 11 | 24 |
| | 1981 | - | - | - | - | - | 6 | 61 | 21 | 3 | 9 | - | - | - | - | - | 41 | 45 | 0.1 | 5 | 9 | 28 | 51 | 8 | 4 | 9 |
| | 1982 | 16 | 24 | 7 | 7 | 46 | - | - | - | - | - | 11 | 34 | 16 | 4 | 35 | 3 | 29 | 14 | 16 | 38 | 12 | 30 | 13 | 7 | 38 |
| | $\bar{X}$ 1972-77 | 25 | 4 | 5 | 6 | 60 | 15 | 22 | 13 | 10 | 40 | 35 | 7 | 7 | 4 | 47 | 29 | 9 | 13 | 6 | 57 | 29 | 7 | 8 | 5 | 51 |
| | $\bar{X}$ 1978-82 | 30 | 35 | 4 | 8 | 23 | 12 | 54 | 15 | 5 | 14 | 9 | 23 | 16 | 18 | 34 | 40 | 28 | 7 | 9 | 16 | 26 | 30 | 10 | 11 | 23 |
| Huarmey-Pisco: 10-14°S | 1972 | - | - | - | - | - | - | - | - | - | - | 24 | 8 | 13 | 11 | 44 | 9 | 0 | 11 | 18 | 62 | 21 | 7 | 13 | 12 | 47 |
| | 1973 | 46 | 2 | 0.03 | 5 | 53 | - | - | - | - | - | 77 | 6 | 2 | 0.7 | 14 | 51 | 12 | 0 | 4 | 33 | 61 | 5 | 1 | 3 | 30 |
| | 1974 | 45 | 6 | 12 | 6 | 31 | 38 | 24 | 18 | 8 | 12 | 65 | 8 | 6 | 3 | 18 | 66 | 0 | 3 | 2 | 29 | 53 | 11 | 10 | 5 | [illegible] |
| | 1975 | 37 | 3 | 14 | 4 | 42 | - | - | - | - | - | 21 | 4 | 4 | 3 | 68 | - | - | - | - | - | 32 | 3 | 11 | 4 | 50 |
| | 1976 | 35 | 2 | 10 | 5 | 48 | - | - | - | - | - | 44 | 24 | 7 | 1 | 24 | 39 | 27 | 10 | 3 | 21 | 37 | 11 | 9 | 5 | 38 |
| | 1977 | 26 | 14 | 36 | 9 | 15 | - | - | - | - | - | 37 | 11 | 9 | 1 | 42 | 33 | 10 | 7 | 4 | 46 | 30 | 12 | 20 | 6 | 32 |
| | 1978 | - | - | - | - | - | - | - | - | - | - | 20 | 9 | 48 | 5 | 18 | 39 | 39 | 12 | 2 | 8 | 34 | 31 | 21 | 3 | 11 |
| | 1979 | 27 | 28 | 18 | 5 | 22 | - | - | - | - | - | 28 | 26 | 12 | 8 | 26 | - | - | - | - | - | 28 | 27 | 15 | 6 | 24 |
| | 1980 | 19 | 29 | 16 | 5 | 31 | 2 | 21 | 18 | 3 | 56 | 43 | 16 | 20 | 2 | 19 | 22 | 18 | 21 | 13 | 26 | 23 | 21 | 19 | 7 | 30 |
| | 1981 | - | - | - | - | - | 25 | 37 | 11 | 8 | 19 | - | - | - | - | - | 43 | 3 | 19 | 3 | 32 | 36 | 17 | 16 | 5 | 26 |
| | 1982 | 21 | 18 | 3 | 2 | 56 | - | - | - | - | - | 23 | 21 | 15 | 4 | 37 | 0 | 27 | 23 | 8 | 42 | 18 | 21 | 11 | 4 | 46 |
| | $\bar{X}$ 1972-77 | 38 | 5 | 12 | 6 | 39 | 38 | 24 | 18 | 8 | 12 | 50 | 8 | 6 | 4 | 32 | 42 | 10 | 5 | 5 | 38 | 43 | 8 | 9 | 5 | 35 |
| | $\bar{X}$ 1978-82 | 23 | 26 | 14 | 4 | 33 | 11 | 27 | 15 | 5 | 42 | 30 | 19 | 21 | 5 | 25 | 30 | 26 | 17 | 7 | 20 | 27 | 24 | 17 | 5 | 28 |
| Pisco-Frontera Sur: 14-19°S | 1972 | - | - | - | - | - | - | - | - | - | - | 14 | 2 | 21 | 1 | 62 | 50 | 0.1 | 17 | 0 | 33 | 24 | 1 | 20 | 1 | 56 |
| | 1973 | 20 | 2 | 0.3 | 3 | 75 | - | - | - | - | - | 42 | 4 | 19 | 0.06 | 65 | 52 | 2 | 6 | 0 | 40 | 35 | 3 | 8 | 1 | 53 |
| | 1974 | 48 | 4 | 3 | 1 | 44 | 57 | 4 | 4 | 8 | 27 | 37 | 7 | 10 | 1 | 45 | 29 | 0 | 2 | 5 | 64 | 45 | 5 | 6 | 4 | 40 |
| | 1975 | 26 | 3 | 23 | 8 | 40 | - | - | - | - | - | 20 | 3 | 14 | 0.7 | 62 | - | - | - | - | - | 24 | 3 | 20 | 5 | 48 |
| | 1976 | 34 | 1 | 26 | 12 | 27 | - | - | - | - | - | 52 | 1 | 10 | 2 | 35 | 64 | 0 | 7 | 1 | 28 | 44 | 1 | 19 | 8 | 28 |
| | 1977 | 16 | 7 | 27 | 6 | 44 | - | - | - | - | - | 16 | 8 | 32 | 1 | 43 | 16 | 10 | 21 | 1 | 52 | 16 | 8 | 26 | 4 | 46 |
| | 1978 | - | - | - | - | - | - | - | - | - | - | 29 | 12 | 30 | 3 | 26 | 23 | 22 | 9 | 4 | 42 | 25 | 18 | 16 | 4 | 37 |
| | 1979 | 10 | 15 | 26 | 6 | 43 | - | - | - | - | - | 14 | 21 | 30 | 8 | 27 | - | - | - | - | - | 12 | 18 | 27 | 7 | 36 |
| | 1980 | 9 | 13 | 26 | 13 | 39 | 22 | 18 | 24 | 6 | 30 | 23 | 15 | 29 | 5 | 28 | 26 | 27 | 27 | 4 | 21 | 21 | 20 | 25 | 7 | 27 |
| | 1981 | - | - | - | - | - | 17 | 13 | 18 | 8 | 44 | - | - | - | - | - | 21 | 22 | 14 | 1 | 42 | 19 | 18 | 16 | 4 | 43 |
| | 1982 | 3 | 4 | 7 | 6 | 80 | - | - | - | - | - | 4 | 5 | 8 | 1 | 82 | 16 | 21 | 24 | 3 | 36 | 6 | 8 | 11 | 4 | 71 |
| | 1983 | 4 | 33 | 24 | 6 | 33 | | | | | | | | | | | | | | | | | | | | |
| | $\bar{X}$ 1972-77 | 26 | 3 | 16 | 6 | 49 | 57 | 4 | 4 | 8 | 27 | 26 | 4 | 18 | 1 | 51 | 43 | 3 | 12 | 1 | 41 | 31 | 3 | 15 | 3 | 48 |
| | $\bar{X}$ 1978-82 | 8 | 12 | 21 | 8 | 51 | 20 | 16 | 22 | 7 | 35 | 16 | 15 | 26 | 5 | 38 | 23 | 24 | 18 | 3 | 32 | 16 | 17 | 22 | 6 | 39 |
| Toda la costa: 3-19°S | 1972 | - | - | - | - | - | - | - | - | - | - | 16 | 3 | 16 | 5 | 60 | 31 | 0.1 | 17 | 4 | 52.9 | 19 | 2.5 | 15 | 5 | 58 |
| | 1973 | 22 | 1 | 0.2 | 3 | 76.8 | - | - | - | - | - | 59 | 5 | 6 | 0.42 | 29.6 | 50 | 6 | 6 | 2 | 36 | 42 | 4 | 4 | 2 | 48 |
| | 1974 | 46 | 5 | 9 | 5 | 35 | 38 | 13 | 10 | 8 | 31 | 36 | 8 | 15 | 5 | 36 | 38 | 7 | 12 | 6 | 37 | 39 | 9 | 11 | 6 | 35 |
| | 1975 | 32 | 3 | 16 | 7 | 42 | - | - | - | - | - | 23 | 4 | 11 | 4 | 58 | - | - | - | - | - | 28 | 3 | 14 | 6 | 49 |
| | 1976 | 36 | 3 | 11 | 6 | 44 | - | - | - | - | - | 46 | 12 | 7 | 2 | 33 | 32 | 19 | 10 | 3 | 36 | 37 | 8 | 10 | 5 | 40 |
| | 1977 | 18 | 15 | 28 | 10 | 29 | - | - | - | - | - | 21 | 21 | 17 | 1 | 40 | 19 | 10 | 14 | 6 | 51 | 18.5 | 14 | 21 | 7 | 39 |
| | 1978 | - | - | - | - | - | - | - | - | - | - | 25 | 15 | 32 | 8 | 20 | 40 | 26 | 8 | 7 | 19 | 36 | 23 | 14 | 7 | 20 |
| | 1979 | 21 | 20 | 18 | 6 | 35 | - | - | - | - | - | 14 | 18 | 19 | 15 | 34 | - | - | - | - | - | 17.6 | 19 | 18 | 10 | 35 |
| | 1980 | 10 | 33 | 17 | 10 | 30 | 17 | 22 | 20 | 7 | 34 | 20 | 20 | 21 | 6 | 33 | 22 | 28 | 19 | 8 | 23 | 17.5 | 26.5 | 19 | 8 | 29 |
| | 1981 | - | - | - | - | - | 14 | 35 | 20 | 6 | 25 | - | - | - | - | - | 30 | 33 | 8 | 2 | 27 | 24 | 33.5 | 13 | 14 | 25 |
| | 1982 | 9 | 15 | 5 | 5 | 66 | - | - | - | - | - | 11 | 21 | 11 | 4 | 53 | 10 | 24 | 22 | 7 | 37 | 10 | 19 | 10 | 5 | 56 |
| | $\bar{X}$ 1972-77 | 28 | 5 | 11 | 6 | 50 | 38 | 13 | 10 | 8 | 31 | 34 | 6 | 12 | 3 | 45 | 35 | 8 | 11 | 4 | 42 | 32 | 6 | 11 | 5 | 46 |
| | $\bar{X}$ 1978-82 | 15 | 23 | 14 | 7 | 41 | 16 | 27 | 20 | 7 | 30 | 16 | 18 | 20 | 10 | 36 | 28 | 28 | 14 | 6 | 24 | 20 | 23 | 16 | 8 | 33 |

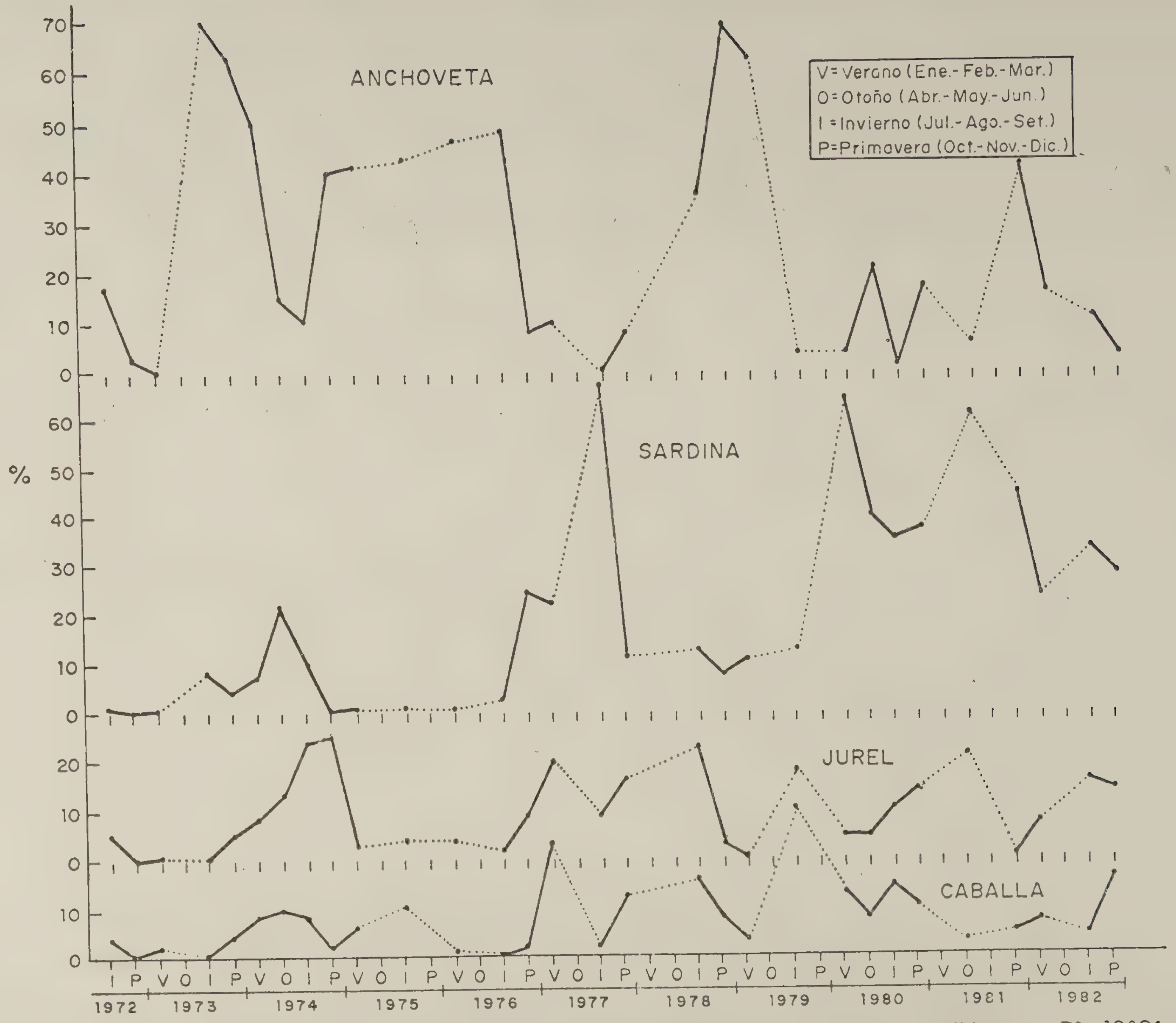


Fig.37 Composición por especies pelágicas (%) por estaciones y años en la zona comprendida entre 7° y 10°S: Pimentel a Huarmey. (Datos de calas de cruceros acústico-pesqueros y eurekas.)

Pelagic species composition (%) by seasons and years at 7°-10°S, Pimentel-Huarmey. (Data from hauls made during Eurekas and Cruises).

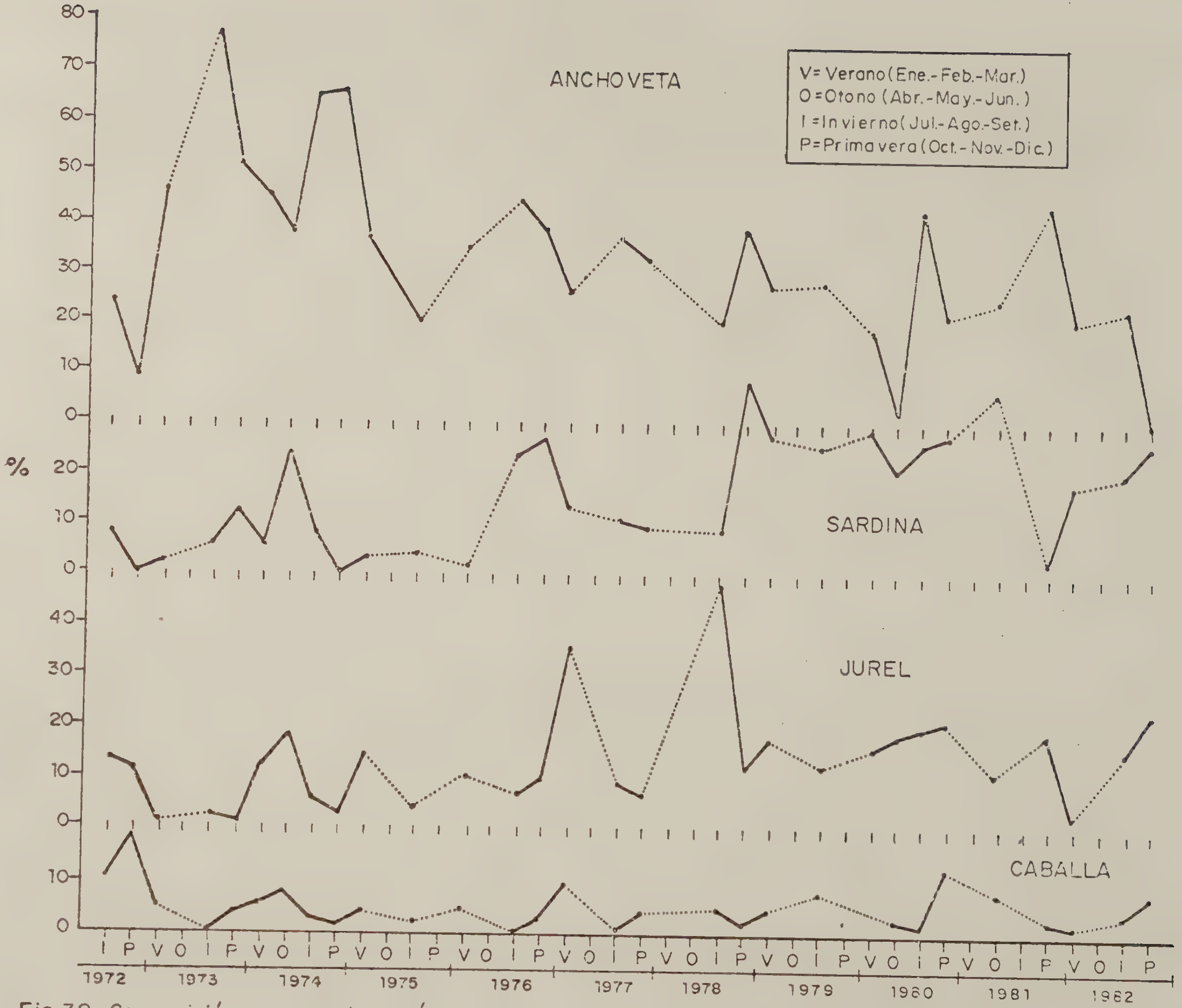


Fig. 38 Composición por especies pelágicas (%) por estaciones y años, en la zona comprendida entre 10° y 14° S: Huarmey a Pisco. (Datos de calas de cruceros acústico-pesqueros y Eurekas.)
Pelagic species composition (%) by seasons and years at 10°-14°S: Huarmey-Pisco (Data from hauls made during Eureka and Cruises.)

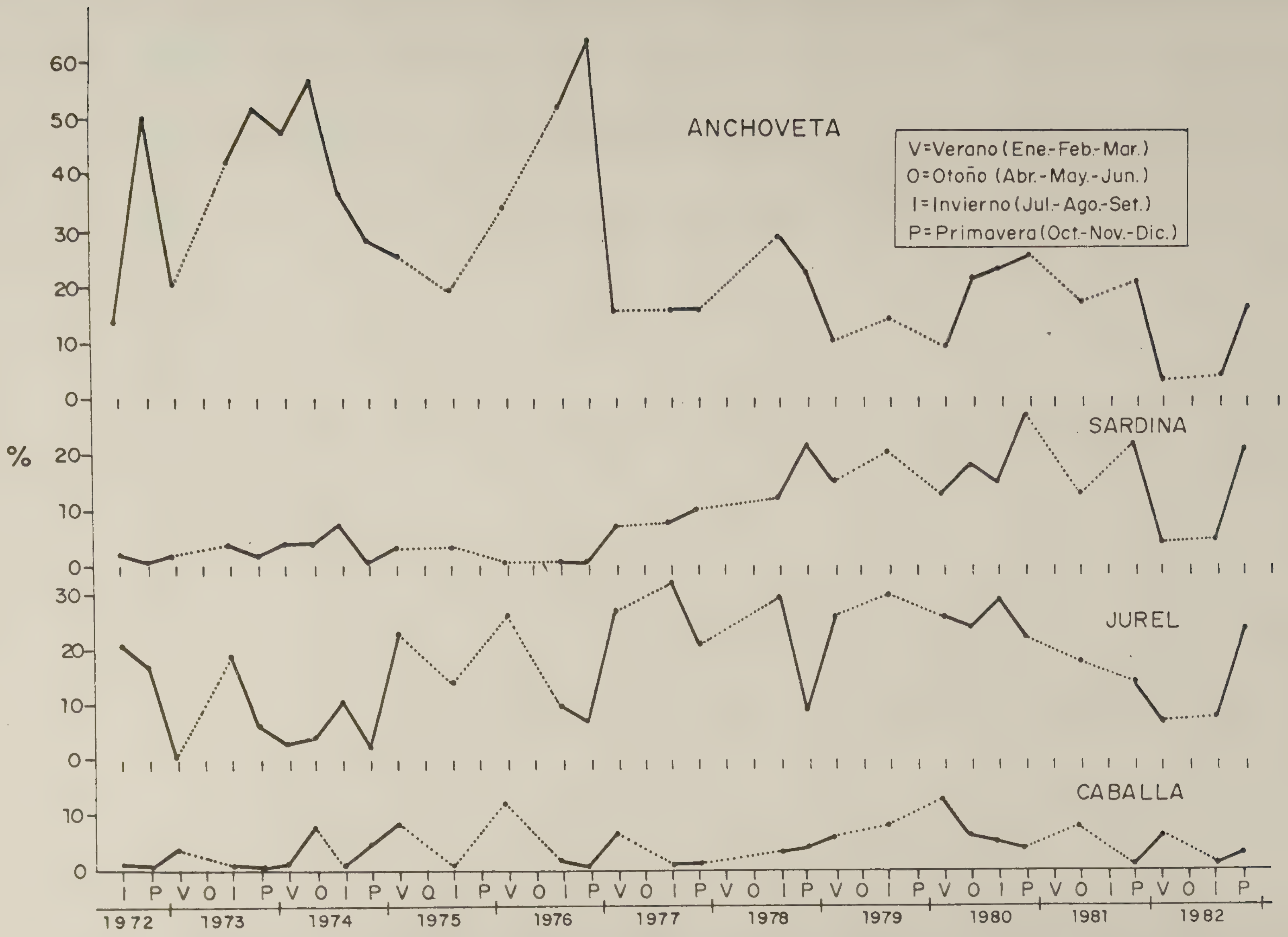


Fig. 39 Composición por especies pelágicas (%) por estaciones y años, en la zona comprendida entre 14° y 19°S.: Pisco a la Frontera Sur. (Datos de calas de cruceros acústico-pesqueros y eurekas.)
Pelagic species composition (%) by seasons and years at 14°-19°S : Pisco-Frontera Sur. (Data from hauls made during Eurekas and Cruises.)

Tabla 3 - Biomasa promedio anual, desembarques y tasas de explotación de la anchoveta en la costa peruana durante 1963-1982 (*).

Annual biomass, landings and exploitation rate of anchoveta along Peruvian coast, during 1963-1982 (*).

| AÑOS<br>Years | BIOMASA PROMEDIO<br>Mean biomass<br>$10^6$ TM | DESEMBARQUES<br>Landings<br>$10^3$ TM | TASA DE EXPLOTACION<br>Exploitation rate<br>$\frac{C}{B} = \frac{F}{F+M}$ (1-exp-Z) |
|---|---|---|---|
| 1963 | 13.4 | 6423 | 0.48 |
| 1964 | 14.7 | 8863 | 0.60 |
| 1965 | 18.6 | 7233 | 0.39 |
| 1966 | 18.5 | 8529 | 0.46 |
| 1967 | 22.0 | 9824 | 0.45 |
| 1968 | 16.8 | 10262 | 0.61 |
| 1969 | 14.2 | 8960 | 0.63 |
| 1970 | 16.0 | 12277 | 0.77 |
| 1971 | 13.4 | 10282 | 0.77 |
| 1972 | 6.6 | 4448 | 0.67 |
| 1973 | 4.9 | 1848 | 0.38 |
| 1974 | 5.4 | 3583 | 0.66 |
| 1975 | 6.8 | 3071 | 0.45 |
| 1976 | 8.3 | 3870 | 0.47 |
| 1977 | 3.0 | 700 | 0.23 |
| 1978 | 3.9 | 1207 | 0.31 |
| 1979 | 3.4 | 1294 | 0.38 |
| 1980 | 1.8 | 566 | 0.31 |
| 1981 | 3.0 | 1167 | 0.39 |
| 1982 | - | 1700 (**) | 0.6 - 0.8 ? |

(*) Tomado de Tsukayama, 1983 (en prensa)

(**) Cifra preliminar

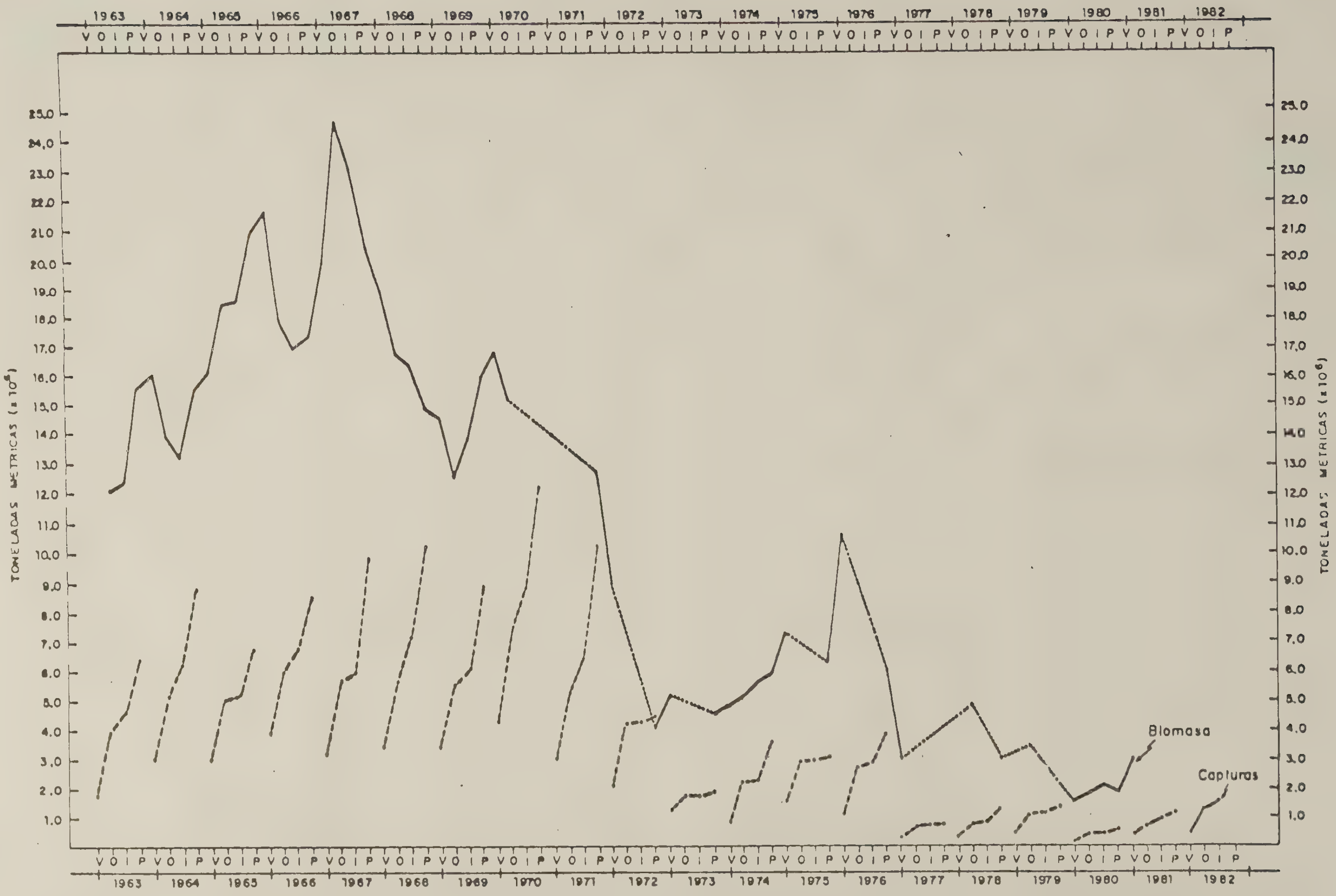


Fig. 4 0 Fluctuaciones estacionales e interanuales de la biomasa de Anchoveta en la costa peruana y capturas anuales (acumuladas por estaciones) durante 1963-82.
Seasonal and annual variations in Anchoveta biomass along peruvian coast and annual catches (accumulated by seasons) during 1963-82.
(De Tsukayama 1983, En prensa)

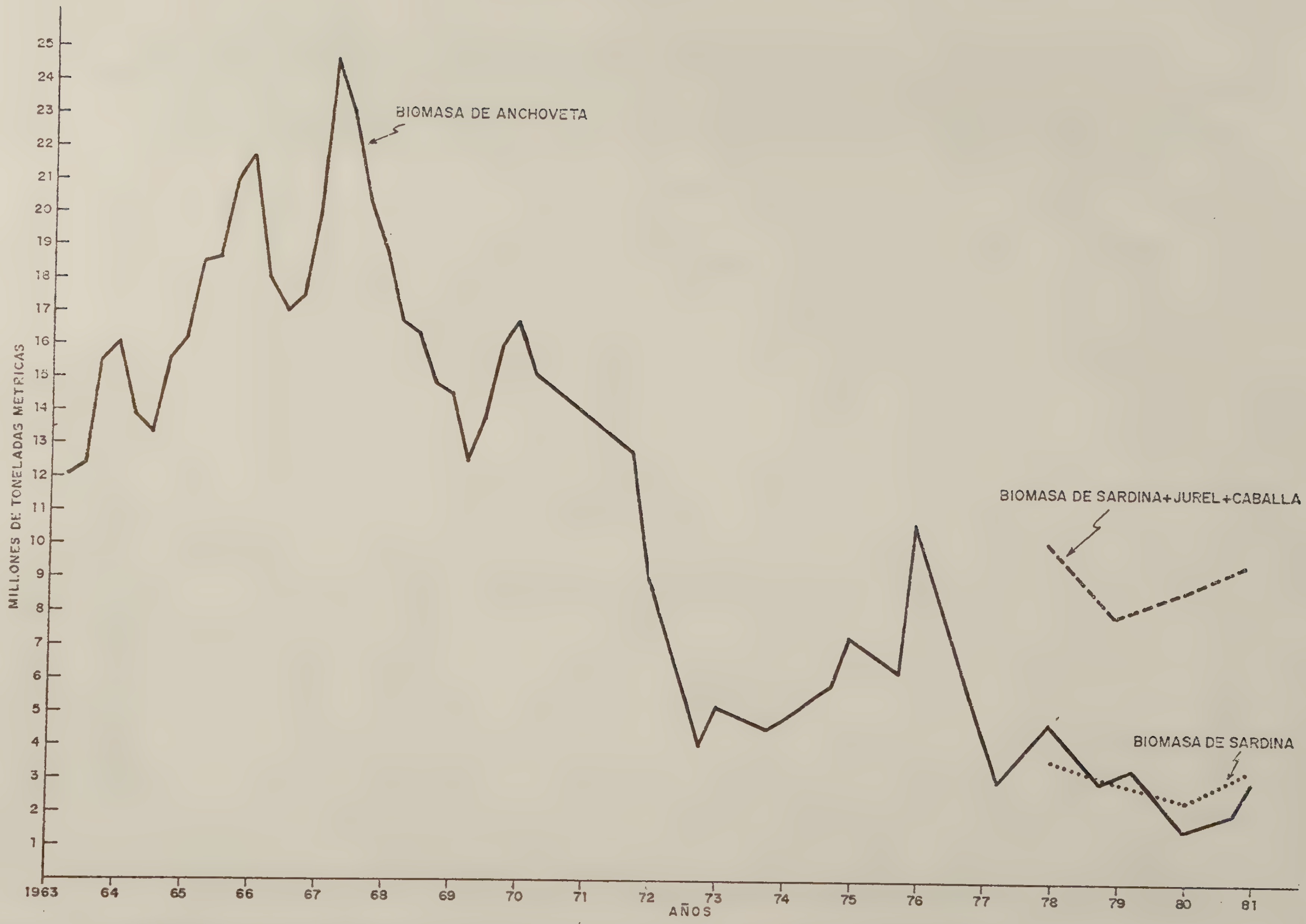


Fig. 41 FLUCTUACION DE LA BIOMASA DE "ANCHOVETA" EN EL PERIODO 1963-1981 Y DE "SARDINA", "JUREL" Y "CABALLA" EN EL PERIODO 1978-1981.
ANCHOVETA BIOMASS FLUCTUATION DURING 1963-81 AND SARDINA, JUREL, CABALLA DURING 1978-81.

anuales 1962 a 1971 durante su fase explotable, indican que la flota capturó proporciones cada vez mayores de ejemplares en su primer año de vida, en relación con el rendimiento total de la respectiva clase anual. Así por ejemplo, la clase anual 1962 rindió 6.48 millones de toneladas durante su paso por la pesquería, de los cuales el 46% fue de ejemplares con menos de un año de edad; en los años 1970 y 1971 dicha proporción se incrementó a 94% y 80%, respectivamente. Estas evidencias sugieren que en los años previos al Niño 1972, las altas tasas de explotación provocaron una "sobrepesca del crecimiento" en el stock de anchoveta, eliminando la oportunidad que los peces pequeños logren su potencial de crecimiento, a diferencia de lo sugerido por Clark (1977) citado por Bakun y Parrish (1981), quien expresa "la posibilidad que el colapso del stock de anchoveta, el cual coincidió con El Niño 1972, pudo deberse a una insuficiente pesca en 1971, así como a una excesiva pesca en 1972".

En estas circunstancias, ocurre El Niño 1972 que precipitó la caída del stock al incidir fundamentalmente en una pobre sobrevivencia de los primeros estados de vida de esta especie, generando a su turno el reclutamiento más pobre registrado hasta esa fecha, que representó 1/7 del reclutamiento promedio de los años 1961-71. Durante 1961-71 en que las condiciones ambientales fueron más estables y la biomasa de adultos fue alta, el reclutamiento varió por un factor de tres veces.

La situación de inestabilidad se acentuó en los años siguientes, en que la población ha continuado sometida a intensa explotación, disminuyendo de esta manera las posibilidades de restablecerse y haciéndola a su vez cada vez más sensible a los cambios aún sutiles del ambiente, con la consecuencia de generar reclutamientos muy pobres que han variado por un factor de 18 veces en el período 1972-78. Esta situación de stress se ha incrementado con la creciente expansión de otras poblaciones pelágicas las cuales exhiben un mayor rango de tolerancia frente a las variaciones del ambiente.

En el período 1978-81 la tasa de explotación es de 0.37. que se consideraba elevada para el nivel poblacional de esos años, cuya biomasa se situó en las 2-3 millones de toneladas, lo cual ha mermado aún más el stock desovante. En efecto, el stock desovante en 1981 ha sido muy reducido, entre 0.6 a 2.0 millones de toneladas, en las regiones norte y central (J. Alheit, comunicación personal).

En 1982, con la ausencia casi total de reclutas provenientes de los desoves de 1981 y capturas de alrededor de 1.7 millones de toneladas, la tasa de explotación debe haber superado la cifra de 0.60. La ocurrencia del Niño 1982-83 en circunstancias aún más críticas que los de 1972-73 y 1976-77, inducen a pensar que las posibilidades de recuperación del stock, tomará un período largo, aún prohibiendo totalmente su explotación.

Con respecto a las otras especies pelágicas: Los estimados de biomasa de la población de sardina, jurel y caballa se han efectuado a partir de 1978, indicando valores de aproximadamente 3.0 millones de toneladas de sardina, 4.5 de jurel y 1.5 millones de toneladas de caballa; haciendo un total de alrededor de 9 millones de toneladas para las tres especies en conjunto (Fig. 41).

Aún cuando no se disponen de estimaciones para años anteriores, las evidencias mostradas con respecto al aumento en su área de distribución y en la composición por especies, permiten inferir que el aumento de la sardina se ha producido a partir de 1972, con la declinación del stock de anchoveta.

Asimismo, las informaciones de desove dadas por Santander (1981) indican que en los años 1966-68 el desove de sardina fue muy pobre y distribuido en el área de Pta. Aguja-Huarmey (6-10ºS); a partir de 1969 se percibe un cierto incremento en el número de huevos y a partir de 1972 se hace más abundante, al mismo tiempo que se amplia su área de desove.

Estos desoves incrementados en 1971-72, aunados a un ambiente propicio, se vieron reflejados en las capturas de sardina mezcladas con la anchoveta, realizados por la flota anchovetera en 1973. Las capturas de sardina que en los años anteriores no sobrepasó las 10 000 toneladas, alcanza en 1973 la cifra de 132 000 toneladas constituidas predominantemente por ejemplares de 12-18 cm y edades aproximadas de 1-2 años (Tabla 4).

Tabla 4. Desembarques anuales de anchoveta, sardina, jurel y caballa en la costa peruana durante 1951-82 (miles de toneladas).

Annual landings of anchoveta, sardina, jurel and caballa along Peruvian coast, 1951-82 (thousand metric tons).

| AÑO | ANCHOVETA | SARDINA | JUREL | CABALLA |
|---|---|---|---|---|
| 1951 | 12 | 1 | - | 1 |
| 52 | 16 | 0.4 | - | 3 |
| 53 | 37 | 0.1 | - | 2 |
| 54 | 43 | - | - | 4 |
| 55 | 59 | - | - | 1 |
| 56 | 119 | - | - | 4 |
| 57 | 326 | - | - | 9 |
| 58 | 737 | 2 | 0.2 | 13 |
| 59 | 1909 | 4 | 0.4 | 9 |
| 1960 | 2944 | 3 | 0.3 | 9 |
| 61 | 4579 | 3 | 0.2 | 12 |
| 62 | 6275 | 3 | 0.7 | 13 |
| 63 | 6423 | 2 | 2 | 8 |
| 64 | 8863 | 10 | 2 | 2 |
| 65 | 7233 | 7 | 3 | 4 |
| 66 | 8529 | 2 | 4 | 8 |
| 67 | 9824 | 2 | 3 | 13 |
| 68 | 10262 | 2 | 3 | 7 |
| 69 | 8960 | 1 | 4 | 7 |
| 1970 | 12277 | 0.4 | 5 | 9 |
| 71 | 10282 | 6 | 9 | 10 |
| 72 | 4448 | 6 | 19 | 9 |
| 73 | 1848 | 132 | 43 | 65 |
| 74 | 3583 | 73 | 129 | 63 |
| 75 | 3071 | 63 | 37 | 24 |
| 76 | 3870 | 175 | 54 | 40 |
| 77 | 700 | 871 | 505 | 46 |
| 78 | 1207 | 1244 | 387 | 112 |
| 79 | 1294 | 1675 | 147 | 108 |
| 1980 | 566 | 1480 | 124 | 59 |
| 81 | 1167 | 1163 | 68 | 42 |
| 82 | 1707 | 1496 | 72 | 19 |

Fuente de información: Instituto del Mar del Perú.
Ministerio de Pesquería.

Tabla 5. Capturas de sardina, jurel y caballa realizadas en el Area Estadística 87 de FAO, según países durante 1975-1980 (miles de TM).

Catch of sardina, jurel and caballa, FAO Statistical Area 87, 1975-1980 (thousand of metric tons).

SARDINA (Sardinops sagax)

| PAISES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|
| Chile | 164.9 | 327.2 | 620.8 | 732.8 | 1618.9 | 1772.7 |
| Perú | 62.9 | 174.7 | 870.9 | 1257.9 | 1727.2 | 1480.4 |
| Rusia | - | - | - | ø | ø | 0.2 |
| TOTAL | 227.8 | 501.9 | 1491.7 | 1990.8 | 3346.2 | 3253.3 |

JUREL (Trachurus symmetricus murphy)

| PAISES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|
| Bulgaria | - | - | - | - | 4.7 | 15.1 |
| Chile | 261.2 | 342.3 | 340.8 | 586.7 | 597.5 | 562.3 |
| Cuba | - | - | - | - | - | - |
| Japón | - | ø | 2.3 | 1.7 | 0.1 | - |
| Korea | - | - | - | 0.8 | - | - |
| Perú | 37.9 | 54.2 | 505.0 | 462.5 | 150.9 | 123.2 |
| Polonia | - | - | - | - | 1.2 | 0.5 |
| URSS | - | - | - | 49.2 | 532.2 | 494.4 |
| TOTAL | 299.1 | 396.5 | 848.1 | 1100.9 | 1286.6 | 1195.5 |

CABALLA (Scomber japonicus)

| PAISES | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|
| Bulgaria | - | - | - | - | 0 | 0.1 |
| Chile | 15.2 | 52.7 | 141.2 | 182.7 | 89.1 | 102.3 |
| Cuba | - | - | - | - | 0.1 | 2.8 |
| Japón | - | - | - | X | X | - |
| Korea | - | - | - | - | - | - |
| Perú | 23.6 | 40.2 | 46.1 | 97.2 | 118.0 | 59.0 |
| Polonia | - | - | - | - | - | - |
| URSS | - | - | - | 1.8 | 5.8 | 41.9 |
| TOTAL | 38.8 | 92.9 | 187.3 | 281.7 | 213.0 | 206.1 |

X menos de 0.5 TM
ø 1-51 TM

Fuente de información: Anuario Estadístico de FAO.

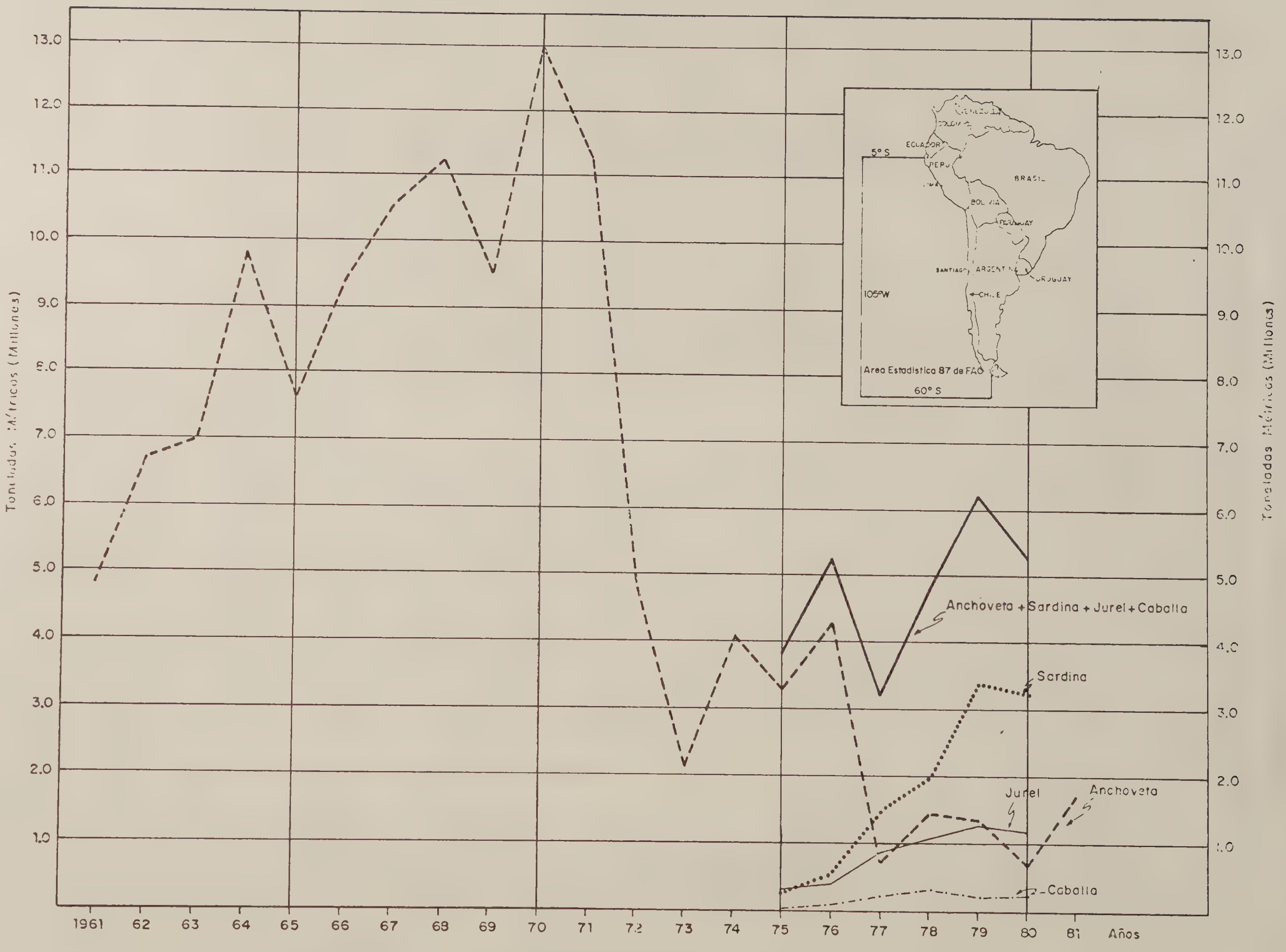


Fig.42 Captura de Anchoveta, Sardina, Jurel y Caballa en el área 87 de FAO.
Catch of Anchoveta, Sardina, Jurel and Caballa in the FAO Statistical Area 87.

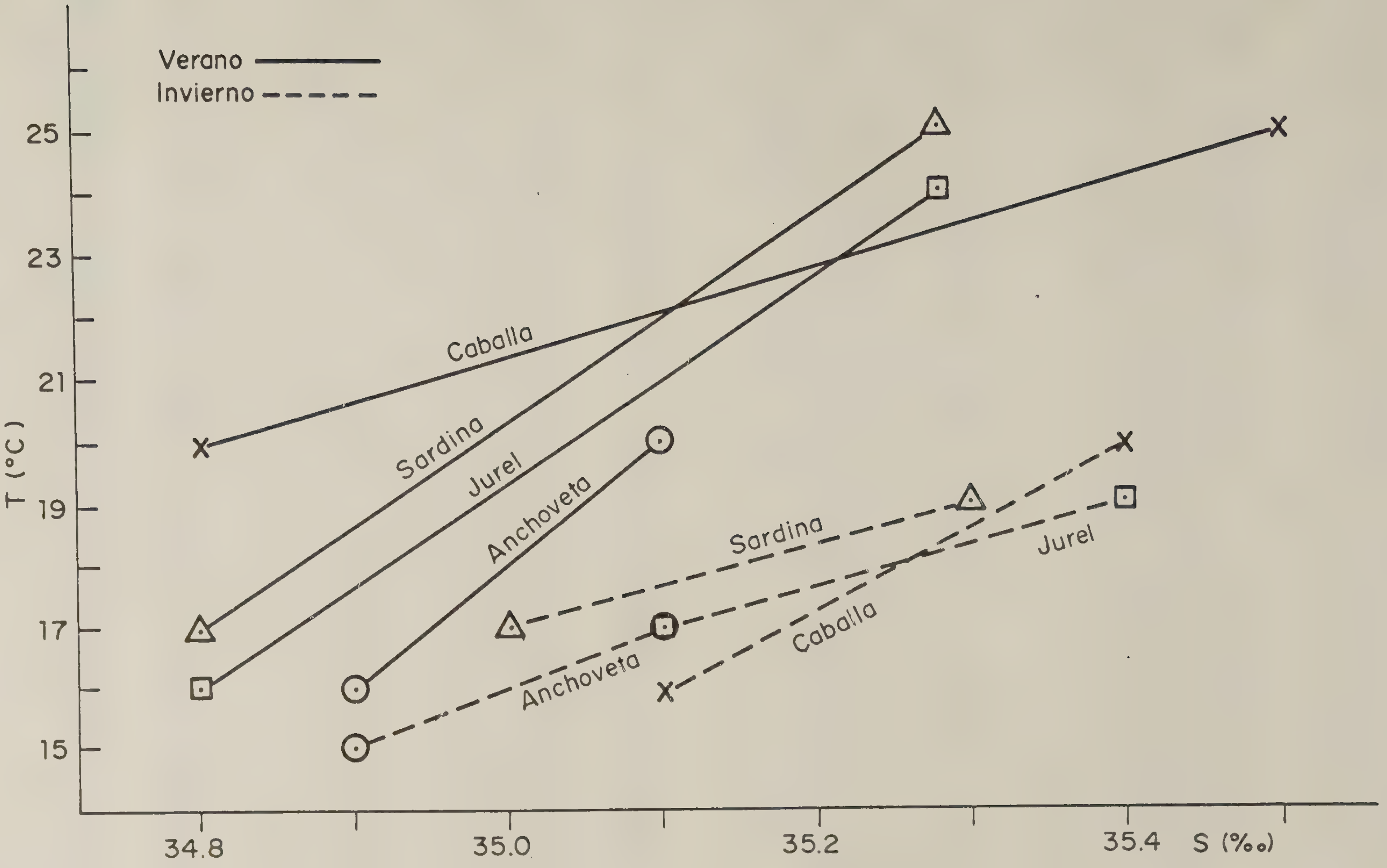


Fig. 43.- Diagrama T-S y rango preferencial tentativo de la Anchoveta (A), Sardina (S), Jurel (J) y Caballa (C).

El número de huevos de sardina graficados por Santander (1981) muestra un mayor incremento en los años 1976-80, lo que aunado a las evidencias mostradas en las secciones anteriores, con respecto a la ampliación de las áreas de distribución y el incremento en la proporción de esta especie, independiente a los datos de desembarque que también se han incrementado sustancialmente, sustentan el hecho que se ha producido un real incremento de la población de sardina.

Para el jurel y la caballa, las evidencias mostradas en las secciones anteriores también indican que se ha producido un sustancial incremento poblacional, no obstante los desembarques de estas especies en la costa peruana son reducidas.

Merece destacarse la tendencia creciente en las capturas de sardina, jurel y caballa en la costa peruana y principalmente en el área 87 de FAO, simultáneamente con la declinación del stock de anchoveta (Figs. 1 y 42, y Tablas 4 y 5). Las fluctuaciones en las poblaciones de sardina, jurel y caballa, dada su amplia distribución, deben observarse a través de todo el Pacífico Oriental usando en lo posible datos independientes de la pesquería. A este respecto, cabe destacar la ejecución del Proyecto Regional "Evaluación de los Recursos Sardina, Jurel y Caballa en el Pacífico Suroriental" con la participación de Ecuador, Perú y Chile, bajo la coordinación del SELA y el apoyo económico del Banco Interamericano de Desarrollo.

## DISCUSION

Uno de los puntos que merece destacarse en el patrón de distribución de las especies estudiadas, de condiciones ambientales diferenciables dentro de un espectro más o menos amplio de las variables ambientales, es la evidente yuxtaposición o traslape. Este hecho se considera de particular importancia en la etapa actual que podríamos denominar de transición, ya que aquella especie que posea e imponga un mayor grado de adaptación o tolerancia a las fluctuaciones ambientales y detente una mayor dispersión que le permita comparativamente tener una menor vulnerabilidad a la pesca, ocupará en el mediano o largo plazo, un lugar preponderante en el ecosistema pelágico, aun cuando no alcance el mismo nivel poblacional o características de la anchoveta de distinto nivel trófico en la cadena alimenticia del mar.

La intensidad y el tipo de interacción generados por la coincidente distribución observada, evidentemente serán elementos definitorios en la estabilidad a largo plazo de determinadas especies en la comunidad pelágica del Pacífico Sur-oriental.

O'Brien (1972) al hacer un análisis estadístico de los vientos del Pacífico, observa un cambio en el patrón de distribución de estos vientos en la década del setenta, en la que se han presentado además dos eventos El Niño (1972 y 1976). Esto podría estar indicando cambios de macro-escala en el sistema océano-atmósfera que podrían haber conducido al evento 1982-83 de características singulares pero también diferentes en muchos aspectos a fenómenos previos y que tuvo como precedente el período 1977-81 de tendencias promedio.

Es probable que estos cambios hayan posibilitado algunas variaciones en los ecosistemas marinos, particularmente en los de régimen costero, lo que a su vez podría explicar en cierta medida la influencia del ambiente en la magnitud y velocidad del incremento de las poblaciones de sardina, jurel y caballa, especialmente estas dos últimas, que no son propiamente de régimen de afloramiento costero como la anchoveta.

A escala local, las fronteras hídricas, los remolinos de dimensiones variables y el flujo de la corriente costera peruana en forma de meandros, establecen un panorama complejo en la distribución de los recursos, reflejado en la conformación de núcleos de concentración de cardúmenes que propician la mayor interacción de especies.

Por otro lado, los períodos cálidos (El Niño) parecen favorecer la competencia de especies en detrimento de los recursos de régimen netamente costero como la anchoveta, y contrariamente, los períodos fríos (anti-Niño) favorecen una expansión de los recursos costeros y la disminución de la disponibilidad para la pesca.

Este hecho nos permite llamar la atención sobre la necesidad de revisar la estrategia de monitoreo dando énfasis a los estudios en series de tiempo, así como a las observaciones simultáneas de ambiente y recurso, dentro de un plan sustentado en hipótesis de trabajo como la que estamos presentando en la Fig. 43, en la que combinamos conocimientos teóricos con observaciones preliminares para graficar curvas del rango ambiental preferencial de las especies anchoveta, sardina, jurel y caballa, tanto para verano como para invierno.

Finalmente, las condiciones descritas también incrementan la interacción a nivel de los primeros estadios de vida, ya sea a través del canibalismo o de la predacción de huevos y larvas, hecho que a su turno determinará en gran medida la fuerza del reclutamiento.

Siendo el reclutamiento el parámetro fundamental del cual depende la magnitud de las poblaciones y al mismo tiempo el que ha mostrado alta variabilidad como producto de las interacciones provocadas por el ambiente, se hace necesario monitorizar la abundancia de los pre-reclutas a fin de coadyuvar a una planificación adecuada de la administración de los recursos pelágicos.

## AGRADECIMIENTOS

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*SOUTH EAST PACIFIC - PACIFICO SUDORIENTAL*

# CHANGES IN THE ABUNDANCE OF PELAGIC RESOURCES ALONG THE CHILEAN COAST

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## Resumen

Se presentan los antecedentes generales sobre la pesquería pelágica Chilena, en relación a su ubicación, extensión geográfica y características oceanográficas, distinguiéndose las unidades de pesquerías que la componen, a saber la de la zona Norte (límite con Perú hasta 25°S), Coquimbo (29°-30°15'S) y Talcahuano (36°10'-37°10'S).

Con la información de las estadísticas de captura, flota y esfuerzo pesquero, expresado como viaje estándar con pesca, se documenta la historia de las dos unidades de pesquerías más importantes, que son Zona Norte y Talcahuano. Se destaca el origen de ambas pesquerías, que ocurrió a principios de la década sesenta y que obedeció a una política de fomento pesquero. Esta produjo un desarrollo explosivo inicial que provocó una gran sobreinversión en la industria pesquera.

El análisis de la distribución geográfica y estructura poblacional de la anchoveta (*Engraulis ringens*), caballa (*Scomber japonicus peruanus*) jurel (*Trachurus murphyi*), sardina común (*Clupea* (*Strangomera*) *bentincki*) y sardina española (*Sardinops sagax*) permite concluir sobre las variaciones ocurridas en la distribución de estas especies, siendo quizás la más espectacular la observada en sardina española, especie que colonizó todo su ambiente, definido por el sistema Humboldt, produciéndose incluso nuevas áreas de desove; por otra parte es dramática la reducción observada en las áreas de desove de la anchoveta.

Las cinco especies analizadas presentan patrones de historia natural similares. Todas son iteróparas y los parámetros de longevidad, crecimiento y primera madurez conforman un patrón consistente, concordante con lo establecido por Beverton (1963). Presentan si diferencias en los patrones geográficos de desove, principalmente entre los clupeoídeos (anchoveta y sardina española) y el jurel. Los primeros se concentran para desovar formando áreas definidas y densas de desove; los segundos en cambio se dispersan distribuyendo los productos reproductivos en grandes áreas de desove. La anchoveta y sardina española desovan en áreas de mayor estabilidad de acuerdo con los conceptos de Lasker (1981) en cambio el jurel desova en áreas de gran transporte de Ekman y alta turbulencia.

Junto con los cambios en la distribución geográfica se observan fuertes cambios en la abundancia de las especies. Los recursos de anchoveta (Zona Norte) y anchoveta-sardina común (Talcahuano) disminuyen su abundancia colapsando en 1977 y 1976 respectivamente. Por otra parte se observa el crecimiento de la abundancia de la caballa, jurel y sardina española, el que se inicia a principios de la década del setenta. El cambio más espectacular de la abundancia ocurre con la sardina española, cuyas capturas crecen desde el nivel de 10 000 ton. en la década sesenta a 1 600 000 toneladas en los últimos años. La segunda especie en importancia es ahora el jurel, cuyas capturas crecen en la zona norte desde 15 000 toneladas en la década sesenta hasta 435 000 ton. en 1981 y en Talcahuano desde menos de 5 000 ton. hasta 400 000 ton. en 1980.

En la pesquería Zona Norte el sistema derivó del dominio de la anchoveta al de la sardina española y en Talcahuano del dominio del recurso mixto anchoveta-sardina común al del jurel. Estas pequerías bien podrían ser definidas como sucesionales.

El cambio de la especie dominante en ambas pesquerías, significó que las capturas totales aumentarán a más del doble.

Los niveles de explotación alcanzados en la explotación de la anchoveta (Zona Norte) y anchoveta-sardina común (Talcahuano) fueron demasiado altos de acuerdo con el conocimiento actual disponible sobre recursos pelágicos, de donde resulta cuestionable culpar sólo a los factores ambientales del colapso de estos recursos.

Es sorprendente constatar que estos recursos cuando se encuentran en la fase de crecimiento explosivo como la experimentada por la sardina española, puedan soportar tasas de explotación extraordinariamente alta (70%) sin demostrar haber sido afectadas negativamente.

La historia de estas pesquerías parece indicar que la combinación tasa de explotación alta junto con condiciones ambientales adversas es muy peligrosa para la permanencia de niveles de abundancia adecuados para la actividad pesquera.

## INTRODUCTION

Pelagic fisheries in Chile are located between the border with Peru and 37° 10' S in the highly productive system of the Humboldt current. It is the most important fishing activity in Chile and represents around 80% of the landings of marine products. Fish meal and oil exports represent a figure close to 250 million dollars, and constitute the third most important export products of the country.

The following three fishery units exist in this area:

- Northern Zone: from the border with Peru to 25°S.
- Coquimbo: 29° 00' - 30° 15' S.
- Talcahuano: 36° 10' - 37° 10' S.

The species supporting these fisheries are mainly the following: anchovy (*Engraulis ringens*), mackerel (*Scomber japonicus peruanus*), jack mackerel (*Trachurus murphyi*) common sardine (*Clupea (Strangomera) bentincki*) and spanish sardine (*Sardinops sagax*). With the exception of common sardine, which only appears in Talcahuano, the remaining species are present in greater or lesser proportion in the three fisheries units at present, which was not always the case.

This paper deals mainly with the Northern Zone fisheries, which began in 1957 in Arica on the basis of anchovy, and with the Talcahuano fishery, which began in 1965, when transformation of the fleet was started. This activity was developed on the basis of mixed common sardine and anchovy resources, which are captured together in varying proportions.

The development of these fisheries, and mainly the Northern Zone fisheries, were the result of development policies in which stock abundance was not properly considered and led to great over-investment. Both fisheries collapsed causing the idleness of a considerable part of the industrial capacity, which subsequently was fully used as a result of a substantial increase of catches due to an impressive growth of spanish sardine and jack mackerel stocks, which were caught in insignificant quantities in the sixties.

The purpose of this paper is to describe these fisheries and the changes they have undergone.

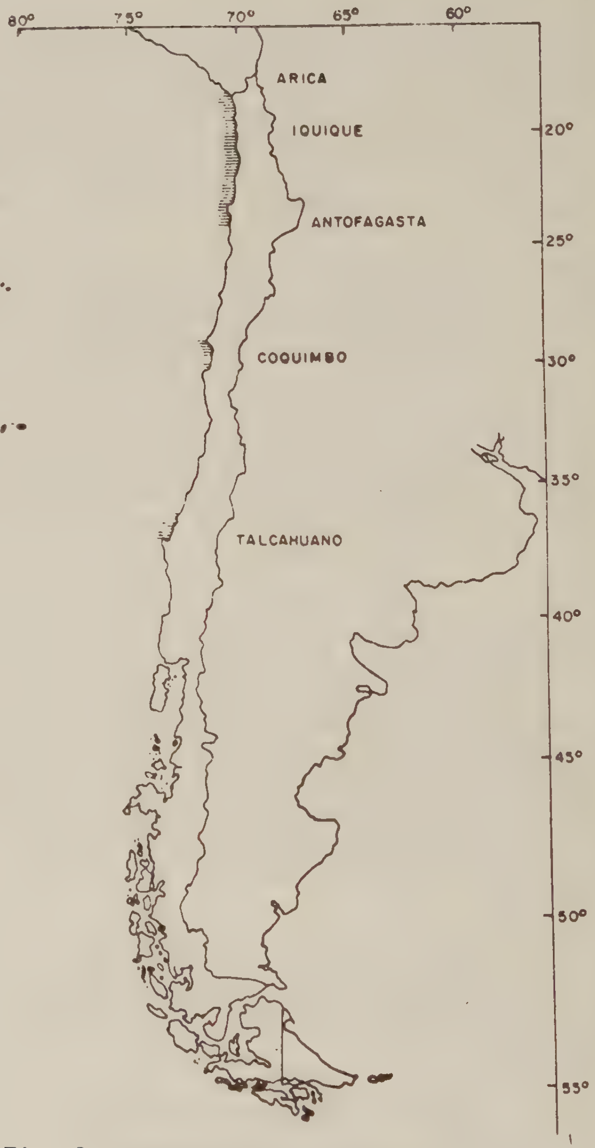


Fig. 1. Geographical location of the chilean pelagic fisheries.

## HISTORY OF THE FISHERIES

### Catches

Northern Zone Fisheries Unit. Figure 2 shows catches of anchovy, spanish sardine, jack mackerel, mackerel and their total, obtained between 1961 and 1981 in the northern zone. The changes in the stocks of these species are clearly reflected by the catches, the most important being the collapse of anchovy (1977) and the change, between 1973 and 1977, from practically monospecific to multispecific fisheries, mainly because of the increase of spanish sardine, jack mackerel and secondarily of mackerel.

Between 1964 and 1971 anchovy went through a "plateau" of high instability; it dropped to a new level in 1972 and collapsed in 1977. Since then it has shown marked fluctuations around the level of 100,000 tons.

Spanish sardine became the dominant species in 1977, surpassing the remaining three in 1979 by a large margin and reaching a peak in 1980 with a record catch of 1,592,000 tons. In 1981 it dropped to 1,425,000 tons.

From 1978 on jack mackerel, with 365,000 tons, became the second species in importance; it decreased in 1979 and 1980, and increased substantially in 1981 reaching a level of 435,000 tons.

Finally, mackerel catches which reached a maximum of 171,000 tons in 1978 after sustained growth, insinuate a decrease, although their behaviour is somewhat erratic.

It is important to stress the level of total catches of fisheries in the Northern Zone in the years when anchovy and spanish sardine were dominant (1967-1971). The level reached since 1979, with spanish sardine as the main species, more than doubles the level reached in the sixties with anchovy.

Talcahuano Fisheries Unit. In this unit fisheries was developed on the basis of the mixed resource of anchovy and common sardine. As in the Northern Zone, it underwent great changes in the composition as regards species and in its catches (Fig. 3).

The mixed anchovy and common sardine resource underwent great fluctuations between 1967 and 1974, and decreased drastically from 164,000 tons caught in 1974 to 47,000 tons in 1975 and then it collapsed in 1966, when 6,600 tons were caught.

As the mixed anchovy and common sardine resource collapsed, jack mackerel catches began to grow showing sustained increases until 1981 with a peak of 406,000 tons.

Spanish sardine began to be caught in this area in 1973. This species was entirely unknown to the fishermen in this zone. Catches increased significantly between 1979 and 1981, reaching a level of 80,000 tons.

In Talcahuano the system passed from the domination of anchovy and common sardine to that of jack mackerel with spanish sardine in second place. The latter species was previously unknown in this latitude. In the Northern Zone this order is reversed spanish sardine being the dominant species.

As in the North, the change in the composition of species and, maybe more app appropriately, the replacement of the dominant species in the system, is the reason for present yields to be more than double than in the previous system in which anchovy and common sardine were dominant.

### Fleet and Fisheries Effort

Northern Zone Fisheries Unit. The fleet in this area is composed of boats of the Pacific Coast Seiner type. It went through a period of accelerated growth between 1962 and 1965, from less than 50 to 251 units, which is the maximum number reached in these fisheries. Later it decreased to 100 units in 1974. Good fishing conditions from 1975 onwards stimulated a new expansion of the fleet which increased to 158 boats in 1981. (Fig. 4) (Serra, in press, Martínez et al. 1981, 1982).

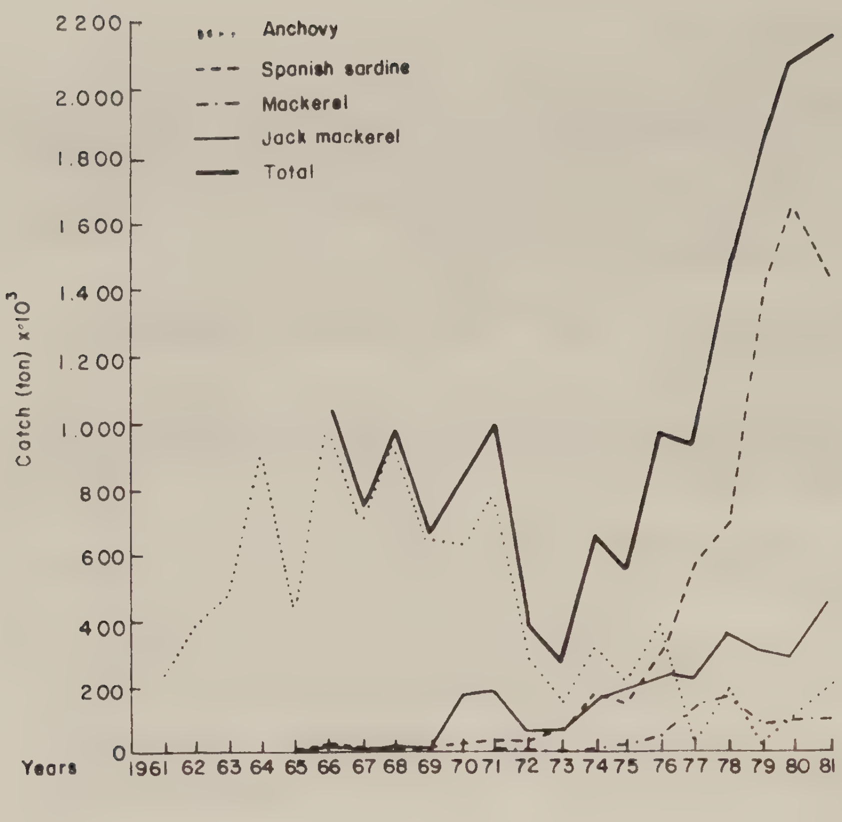


Fig. 2. Total catch, by species, taken in the Chilean northern pelagic fishery (1961-1981).

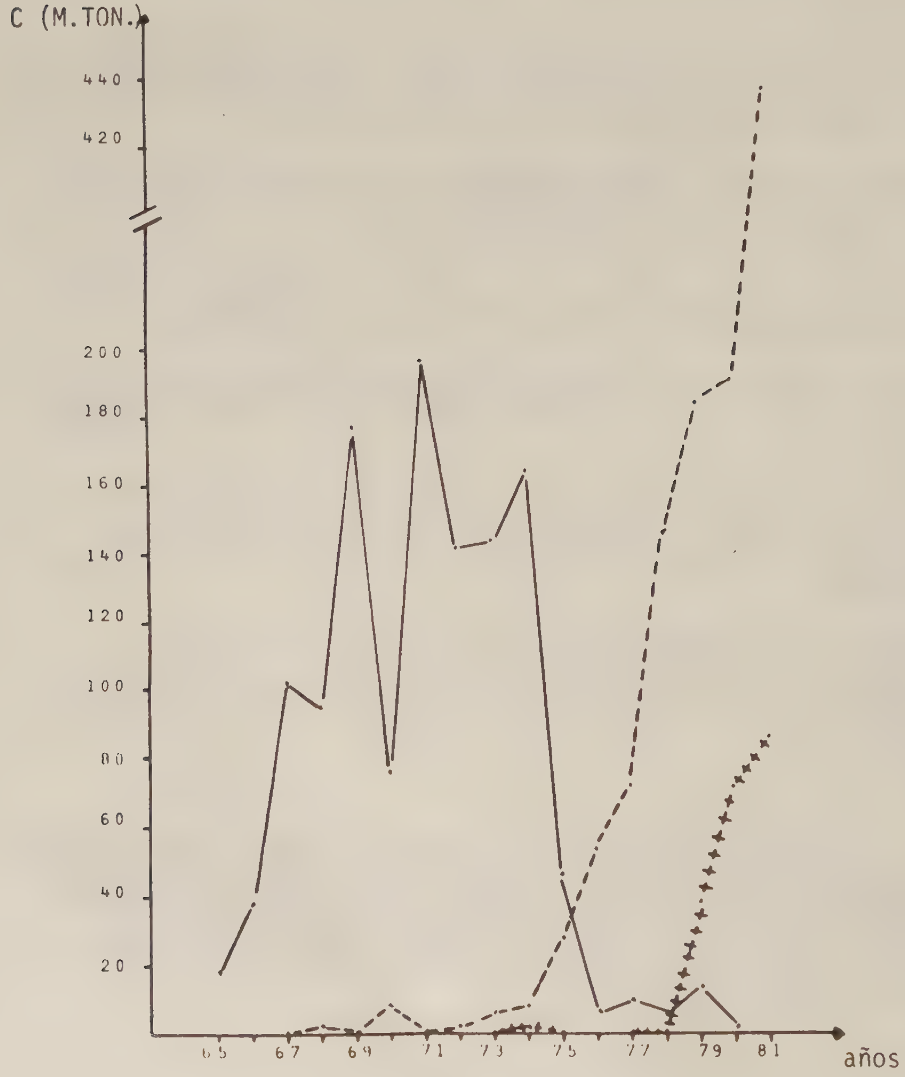


Fig. 3. Industrial catches of anchovy-common sardine (-) jackmackerel (---) and spanish sardine (+++) of the Talcahuano fishery.
(Data Source: IFOP)

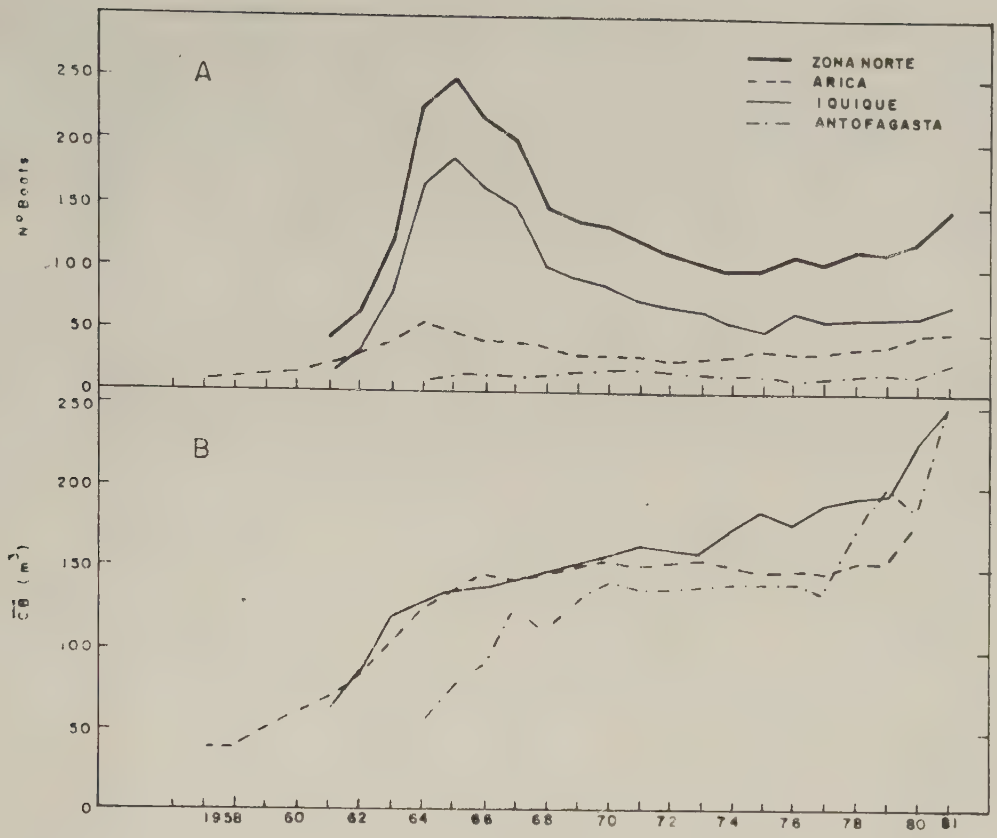


Fig. 4. Evolution of the fleet of the Chilean northern pelagic fishery (1958-1981). A. number of boats B. boat size, expressed as mean hold capacity.

From Serra (in press)

The seiner fleet in the Northern Zone is composed of three small fleets, which operate out of the most important ports, i.e., Arica, Iquique and Antofagasta (including Mejillones). The greatest changes take place in the fleet operating out of Iquique which generally takes the lead in changes introduced in the fleet of these fisheries.

The increase in size of the boats is expressed by average fish hold capacity measured in cubic meters. Figure 4 also shows the evolution of the size of the boats of Arica, Iquique and Antofagasta (including Mejillones). The increase of the average capacity of the fish hold is the result of the incorporation of larger fishing units, withdrawal of the older and smaller units, transfer to other ports and also to other fisheries, such as Talcahuano, for example (Serra, 1978). It may also be observed that most of the renewals of the fleet are made in Iquique, where the curve continued to increase after 1970; on the other hand, it becomes stabilized in the other ports. In recent years, 1980-1981, the average fish hold capacity reached levels of 250 cubic meters.

Serra (in press) states that together with the historical growth of the fleet there is a gradual improvement in fishing gear, such as the incorporation of the power block, absorbent pumps, acoustic equipment, larger nets, airplanes for surveying activities and collaboration in fishing operations. Later, in 1978, other changes were made such as the replacement of the 13 mm mesh size anchovy net by a 38 mm mesh size sardine net. The replacement of practically all the nets was completed by the end of 1979. Neverheless, when large concentrations of anchovy are detected the sardine nets are exchanged for anchovy nets. This process takes place mainly in Arica.

The fleet of the Northern Zone operated only in daytime up to 1974, when nighttime fisheries were stated and gradually increased; in 1978 they were intensified through the incorporation of airplanes for nighttime aerial surveys.

Due to the difficulty of obtaining data regarding the time spent in searches, which in addition is very difficult to measure because of the "airplane effect", the fishing effort is measured by the number of trips. Two units are used: total standard trips and standard trips with catch. The total number of trips is obtained by adding the fishing and non-fishing trips. The criterion used to estimate the effort per species is to assign fishing trips to the dominant species of the catch, to which non-fishing trips are added when measured as total number of trips. The effort is standardized with respect to the size of the boats, using the 130 to 179 cubic meters fish hold as the standard size.

Figure 5 shows total catches and the gross effort expressed as the total number of trips for all species. If it is considered that the total catch is a measure of the stocks (r=0.67; 20 d.f). Another important conclusion is that notwithstanding the lower number of fishing units existing at the end of the seventies and beginning of the eighties, with respect to the maximum of the sixties (Fig. 4), the total number of trips for all species was similar. This proves the great efficiency achieved by the industrial seiner fleet.

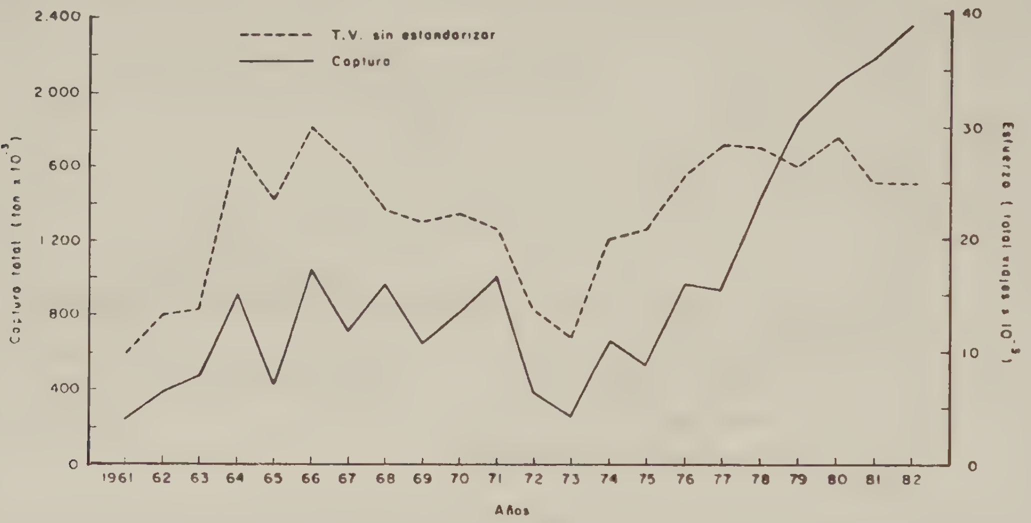


Fig. 5. Total catch and gross effort in the Northern Zone fishery.
Captura= catch; esfuerzo (TV) = effort.

Figure 6 shows the history of anchovy fisheries and the explosive development of the fishing effort measured by the total number of standard trips.

Talcahuano fisheries unit. As in the Northern Zone the fleet in this area is composed of seiners of the Pacific Coast Seiner type. It totalled a maximum of 48 boats in 1969 (Fig. 7), declined until 1972, after which it increased and became stabilized between 1974 and 1976 at an intermediate level of 37 to 39 boats. (Serra, 1978). Subsequently, it continued to increase until it reached a total of 56 boats in 1981 (Martínez, Böhm and Salazar, 1982).

In 1965 the average size of a boat, measured by the capacity of the fish hold, was of approximately 50 cubic meters; it grew rapidly until 1970 reaching a level of 120 cubic meters; it remained relatively stable in the following years and underwent a new phase of growth in recent years, reaching 152 cubic meters (Fig. 7).

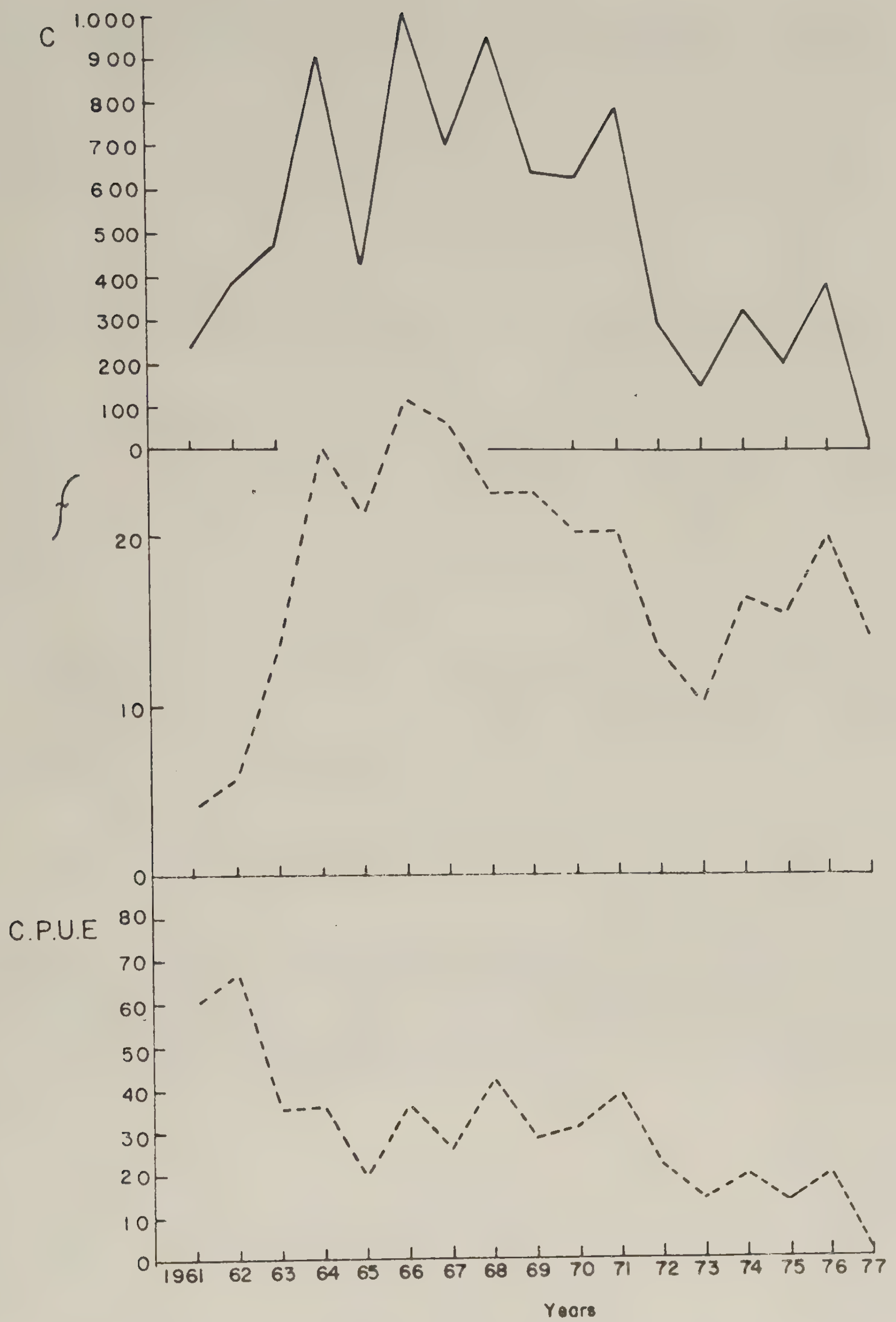


Fig. 6. Catch, effort and cpue of the Chilean anchovy fishery of the northern zone. 1961 - 1977.

From Serra (in press)

Serra (1978) discussed the transformation that took place in the Talcahuano fleet, where the new boats incorporated, mainly in the development phase of these fisheries (1965-1969) were better equipped with acoustic equipment, power blocks, absorbent pumps and larger nets. The original anchovy nets were replaced in 1969 by jack mackerel nets, with a mesh size of 50 mm. Nighttime fishing is another innovation that was introduced in 1979, fundamentally to catch spanish sardine.

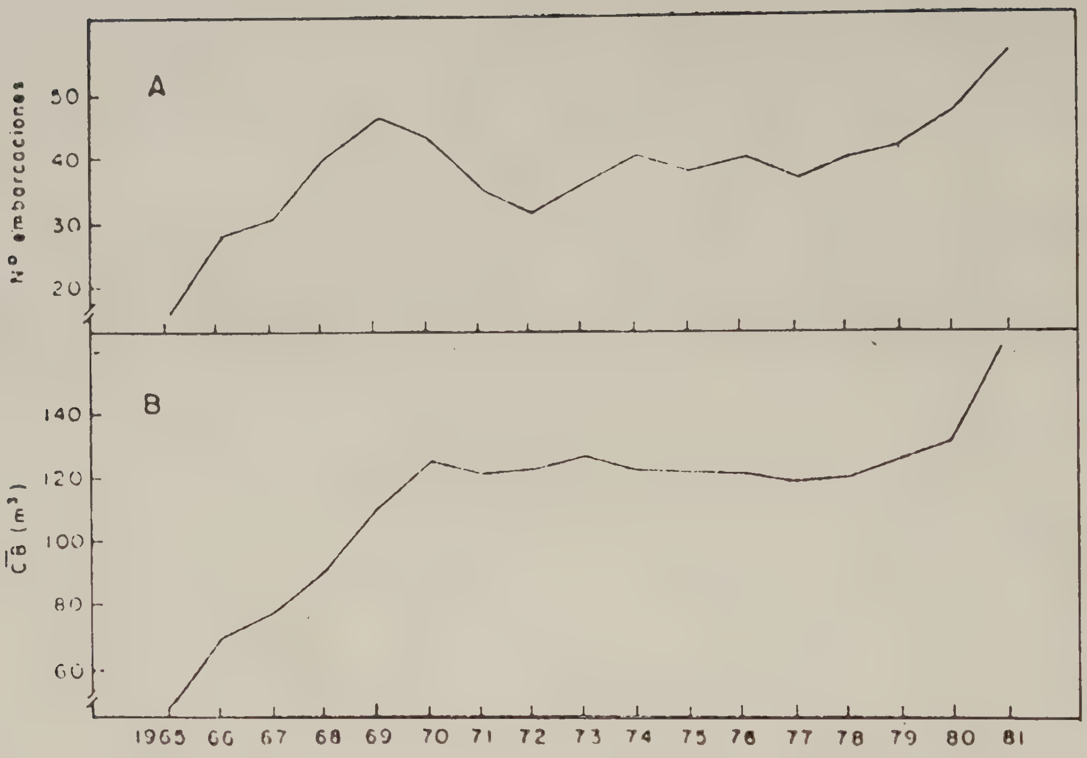


Fig. 7. Evolution of the fleet of the Talcahuano fishery (1965-1981). A: number of boats. B: boatsize expressed as mean hold capacity.

From Serra (1978) actualized with data from Martínez, Bohm and Salazar (1982).

Figure 8 shows the development of the fishing efforts for anchovy and common sardine, which grew considerably in the initial phase and declined after having reached the maximum level of 6,351 standard trips in 1970. The present level is shown in Figure 9 and refers to the effort applied to jack mackerel fisheries and is expressed as total standard trips and standard trips with catch, as in the case of the Northern Zone fisheries.

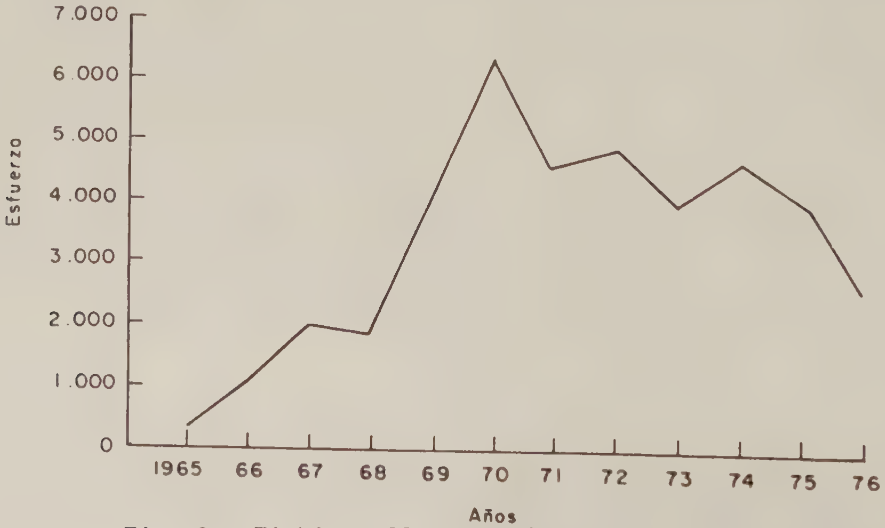


Fig. 8. Fishing effort on the anchovy-common sardine fishery of Talcahuano, expressed as standard trips refered to the 140-149 $m^3$ hold capacity boat size.

From Serra (1978). Esfuerzo=effort; años=years

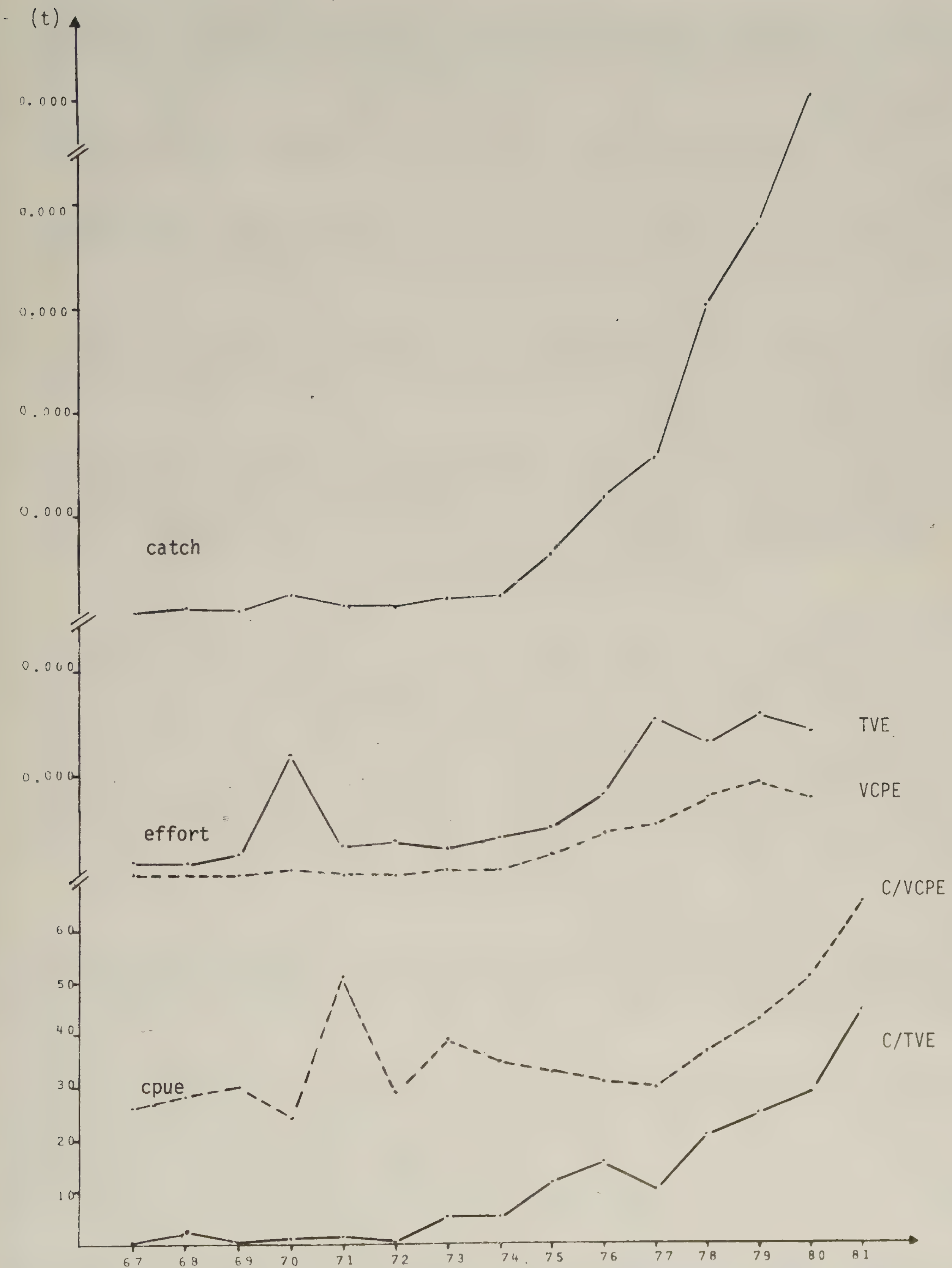


Fig. 9. Catch, effort and cpue of the jack mackerel from the Talcahuano fishery.
From Serra and Zuleta (1982)
TVE: total standard trips; VCPE: standard trips with catch.

## OCEANOGRAPHIC FEATURES

This zone corresponds to the eastern border of the anticyclonic gyre of the Southern Pacific, whose southern boundary is the drift of the western wind, which hits the Chilean coast at approximately 43$^{0}$ latitude south, originating the Humboldt System. The latter is basically formed by three permanent currents and by a complex system of occasional flows and counterflows.

The zone has been typified as one of "eastern border currents", with slow and wide flows in the direction of Ecuador, formed by the coastal and oceanic branches of the Humboldt current, separated by the countercurrent from Peru.

The superficial dynamics of the area are dominated by the Permanent High Pressure Center of the Southern Pacific, whose variability, associated with the concept of Southern Oscillation, conditions the local characteristics of the Chilean sea.

The masses of water described in this area, present a transition zone on the surface where the Sub-Antarctic Water from the South meets with the Sub-Tropical Water which intrudes from the North West. Immediately beneath these there is an intrusion of Subsurface Equatorial Water towards the South; in turn, Intermediate Antarctic Water flows beneath this towards the North.

In general, the area presents great variability in its characteristics, quickly showing the changes from the atmospheric system, which sometimes conditions the existence of cold flows, upwelling, high productivity; and other times warm flows, with invasion of sub-tropical waters and low productivity. It may be said that oceanographically the area is generally highly unstable.

## DISTRIBUTION AND STRUCTURE OF POPULATIONS

### Anchovy (*Engraulis ringens*)

Anchovy lives along the coasts of Perū and Chile. From Zorritos, 4$^{0}$30'S (Chirichigno, 1974), as far as Chiloē, around 42$^{0}$30'S (Brandhorst, 1963).

Along the Chilean coast it is caught mainly along a coastal strip of not more than 25 to 30 nautical miles; however, its distribution surpasses 50 nautical miles offshore.

Meristic, morphometric and marking studies, and reproduction areas indicate the existence of three populations: Center-North of Perū; South of Perū and North of Chile; and Center-South of Chile (Brandhorst, Carreño and Rojas, 1965; Tsukayama, 1966 and 1982; Rojas de Mendiola, 1971; Jordan and Mālaga, 1971; Serra and Gil, 1975).

### Mackerel (*Scomber japonicus peruanus*)

Mackerel is distributed in the South Eastern Pacific from Manta (0$^{0}$45'S) and around the Galāpagos Island (Chirichigno, 1974) south of Guamblin Island, as far as latitude 45$^{0}$41'S, in accordance with observations made in April and May 1978 by A. Sanhueza (pers. com.).

Mann (1954) indicates that mackerel in Chile is present from the border with Perū as far as Valparaīso (33$^{0}$S), but pointed out that it is rarely seen south of Taltal (25$^{0}$20'S).

Catches are mainly obtained along a 60 nautical mile coastal strip. Catches obtained in the region by a fleet of Soviet factory ships indicate that the species is also found beyond 200 nautical miles. (Statistical Year-book, FAO. 1979 and 1980). This information is in agreement with the presence of larvae as far as 200 nautical miles (Rojas and Mujica, 1981).

There is not much information on the populational structure of mackerel in the region, except for the greater increase between hyaline rings of otolith of this species in Ecuador than in Chile, due to which it is assumed that growth is more accelerated in Ecuadorean waters (S. Pizarro and H. Steffens). On the other hand, information obtained from studies in spawning areas (Santander and Castillo, 1979; Serra et al, 1982; Rojas and Mujica, 1981) suggests the existence of two populations: Center-North of Perū and North of Chile.

### Jack mackerel (*Trachurus murphyi*)

Jack mackerel lives along the coasts of Peru and Chile. It is distributed in the area from Lobos de Afuera Island (6°50'S) and around the Galāpagos Islands (Chirichigno, 1974) as far as the mouth of the Strait of Magellan (52°30'S) (Bahamonde, 1978).

It is important to point out the longitudinal distribution of jack mackerel which goes beyond 200 nautical miles (catches of Soviet factory ships); it is found as far as 900 nautical miles from the Chilean coast in accordance with ichthyoplankton studies carried out by Rojas (1980).

The vertical distribution of jack mackerel may be very deep. In the northern zone it has been observed at depths of as much as 200 meters, and in the central-southern and austral zones at depths of 300 meters, where it appears in catches obtained with demersal trawls.

There are no studies nor background information available to indicate the number of populational units existing along the entire distribution area.

### Common sardine (*Clupea (Strangomera) bentincki*)

Common sardine is found from the north of Coquimbo (29°S) as far as Puerto Montt (42°S) (Arrizaga, 1981). This species is mainly coastal and it is caught preferably in the area of Talcahuano (37°S), in gulfs and bays.

There are some meristic data (Brandhorst, Carreño and Rojas; 1965) and data on growth parameters (Aguayo and Soto, 1978) which suggest the existence of two populations of common sardine; one in Coquimbo and the other in Talcahuano.

### Spanish sardine (*Sardinops sagax*)

Spanish sardine is distributed in an area from Southern Ecuador, where it is identified as Peruvian sardine, and around the Galāpagos Islands (Chirichigno, 1974) as far as Corral (39°50'S) in the Center-South of Chile, in accordance with new records of Spanish sardine eggs in August 1981 (Rojas and Mujica, in preparation).

It may be stated according to available information that the geographic distribution of this species has changed. Chirichigno (1974) recorded Secchura By, in Northern Perū, as the northern limit of its distribution. In accordance with different authors the southernmost point at which it is found is:

- Tomē (36°30'S): Delfin (1900) and Fowler, 1945.
- Coast of Concepciōn (36°40'S): C. Oliver Schneider, 1943
- Mocha Island (38°20'S): Mann, 1945

However, other authors indicate that it was not found south of Coquimbo at the end of the fifties (De Buen, 1958) or at the beginning of the sixties (Brandhorst, 1963). This appears to be confirmed by observations carried out by biologists of the Fisheries Development Institute (IFOP), in the mid-sixties in Coquimbo, where although Sardinops appeared in the catches, Clupea was evidently dominant.

Subsequently, at the end of the sixties and beginning of the seventies, Sardinops began to predominate over Clupea in the catches, until the latter finally disappeared. Samplings of landings in Talcahuano from 1965 onwards, by IFOP, confirm the absence of Sardinops in that area in those years.

The longitudinal distribution of spanish sardine reaches 200 nautical miles. However fisheries are carried out preferably within the 60 nautical mile coastal strip.

There are no studies to distinguish the present populational structure, nevertheless, information drawn from the distribution of eggs and larvae (Rojas and Mujica, 1981) suggest the hypothesis that in Chile there are two populations, one in the northern zone and the other in front of Talcahuano. Spatial spawning patterns suggest the existence of another population distributed along the central and northern coast of Perū (Santander, 1981).

## REPRODUCTION

It may be ventured on the basis of an analysis of the spawning seasons (Table 1) of anchovy, mackerel, jack mackerel, common sardine and spanish sardine, that there are two groups: the clupeids on the one hand, with bimodal spawning in the winter and spring and a secondary spawning in the summer; and on the other, mackerel and jack mackerel which ha only one spawning season, in the summer-autumn and spring-summer respectively.

Table 1. Reproductive features of the analysed species.

| Species | Main Spawning Season | First Maturity | $L_M/L_\infty$ |
|---|---|---|---|
| Anchovy | July-August and December | 12 cm. L.t. | 0.63 |
| Mackerel | January-May | 30 cm. L.h. | 0.67 |
| Jack mackerel | October-February | 31 cm. L.h. | 0.48* |
| Common sardine | July-August and January | 11 cm. L.t. | 0.62 |
| Spanish sardine | August-October and February | 24 cm. L.t. | 0.57 |

* It was used $L_\infty$ = 65 cm., L.t.= total length, L.h.= fork length.

The first sexual maturity of the described species occurs when they have reached from 50 to 67% of their asymptotic length, which is interpreted as an adaptive strategy in which the initiation of the reproductive process is retarded in favour of a greater use of energy in the process of growth.

It has been concluded from an examination of the gonads that all the species considered have a fractional spawning system (in batches).

In Chile two areas are considered as the most important spawning grounds of anchovy (Fig. 10), that is the northern zone (between the border with Peru and 25°S) and the area of Talcahuano (35°S to 38°S). In the northern zone spawning areas are close to the coast, mainly among a strip of 20 nautical miles. They may extend as far as 80-100 nautical miles from the coast. In Talcahuano the most important area lies between the Gulf of Arauco (37°10'S) and Punta Nugurue (36°S), and does not extend farther west than 10 to 12 nautical miles (Mujica and Rojas, 1980).

During 1980 ichthyoplankton surveys were carried out between the border with Perú and Coquimbo (39°S) and in the area of Talcahuano (Rojas and Mujica, 1981) which show the important changes in the geographic extension and intensity of spawning of anchovy in the north (Fig. 11). In front of Talcahuano the density of eggs and larvae remains at levels similar to those recorded in the sixties and beginning of the seventies.

Available information indicates that in Chile mackerel spawns mainly in the north, between the border with Perú and Antofagasta (24°S), although larvae have also been reported in front of Talcahuano (Rojas and Mjuica, 1981). Preliminary results of surveys carried out in 1981 and the beginning of 1982, suggest the existence of secondary spawning in the area around Talcahuano (37°S) in the months of September-October (Rojas and Mujica, pers. com.). Distribution of larvae towards the west exceeds 190 nautical miles.

Jack mackerel spawns along the Chilean coast as far as 41°S, which is the southernmost point at which samples have been obtained, not taking into account the distribution of eggs and larvae (Fig. 12). Available information indicates that the largest concentrations of jack mackerel eggs and larvae are located from Antofagasta to the south. Surveys along the Chilean coast were made as far as 200 nautical miles, recording important densities of eggs and larvae in the entire area surveyed, without cutting off its distribution towards the west. Rojas (1980) when analyzing samples of ichthyoplankton taken during a tuna survey in 1979 along the Chilean coast, found a high concentration of jackmackerel larvae

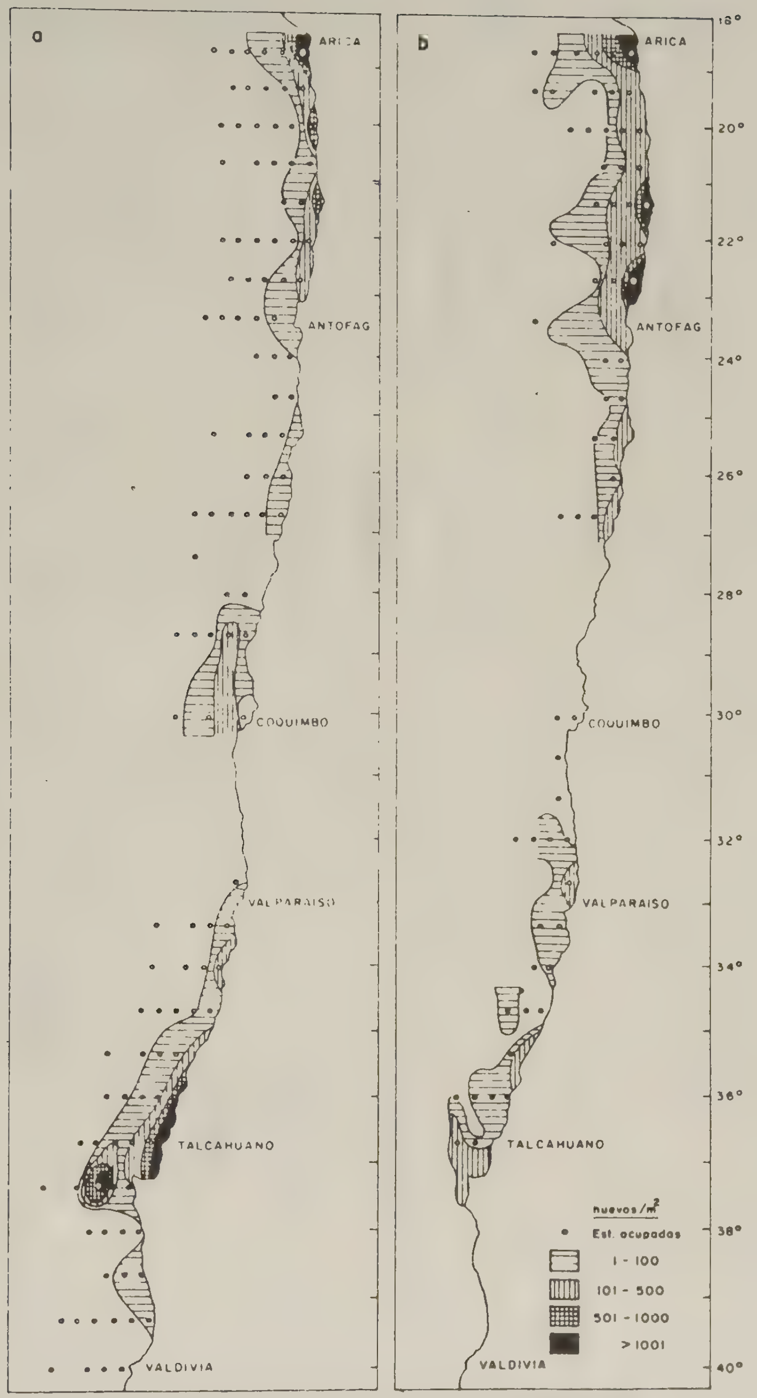
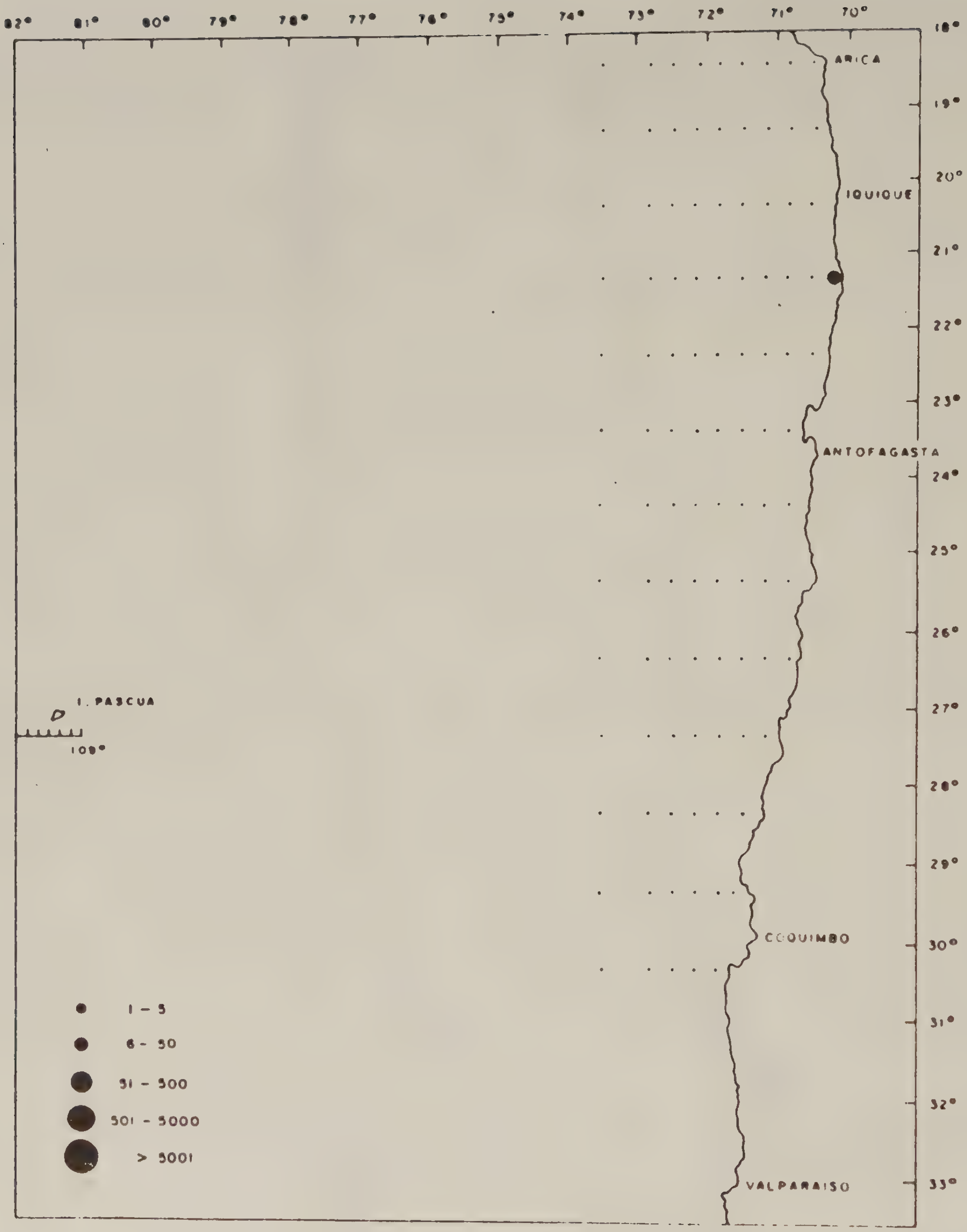

a
b
ARICA
ANTOFAG
COQUIMBO
VALPARAISO
TALCAHUANO
VALDIVIA
18°
20°
22°
24°
26°
28°
30°
32°
34°
36°
38°
40°
huevos/m²
● Est. ocupados
1 - 100
101 - 500
501 - 1000
> 1001

Fig. 10. Geographic distribution of anchovy eggs, 1964-1973.
a) Spring-Summer spawning (November to January)
b) Winter spawning (July to September)
From Serra, Aguayo, Rojas, Cañon and Inostroza (1970). Anchovy (*Engraulis ringens*). In: Estado Actual de las Principales Pesquerias Nacionales. Bases para un Desarrollo Pesquero. CORFO/Instituto Fomento Pesquero. AP 79-18. 52 p.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31°
32°
33°
ARICA
IQUIQUE
ANTOFAGASTA
COQUIMBO
VALPARAISO
I. PASCUA
109°
1 - 5
6 - 50
51 - 500
501 - 5000
> 5001

Fig. 11. Anchovy spawning area in January 1980. From Rojas and Mujica (1981).

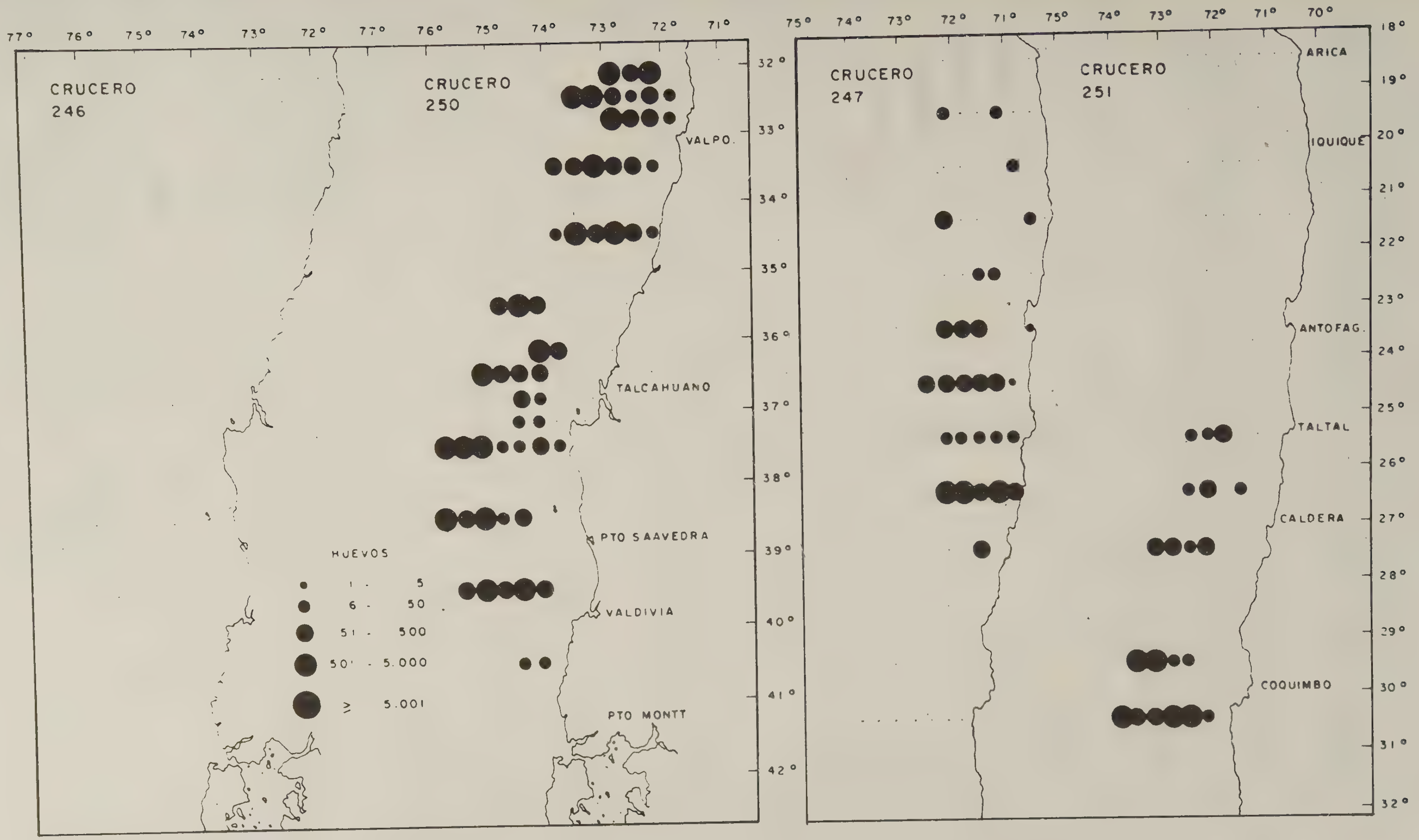
CRUCERO 246
CRUCERO 250
CRUCERO 247
CRUCERO 251
VALPO.
TALCAHUANO
PTO SAAVEDRA
VALDIVIA
PTO MONTT
ARICA
IQUIQUE
ANTOFAG.
TALTAL
CALDERA
COQUIMBO
HUEVOS
1 - 5
6 - 50
51 - 500
501 - 5.000
≥ 5.001
77° 76° 75° 74° 73° 72°
77° 76° 75° 74° 73° 72° 71°
75° 74° 73° 72° 71°
75° 74° 73° 72° 71° 70°
32° 33° 34° 35° 36° 37° 38° 39° 40° 41° 42°
18° 19° 20° 21° 22° 23° 24° 25° 26° 27° 28° 29° 30° 31° 32°

Fig. 12. Spawning area of jackmackerel.
A. August
B. September-October
C. November
D. February.
From Rojas and Mujica, (pers. com.).

in an area offshore of Talcahuano between 450 and 900 nautical miles. The density averaged 23 larvae per positive station, which constitutes a high stocking figure for this area. The characteristic of jackmackerel is its dispersed spawning pattern. The greatest number of eggs found per station was 2,400 (Rojas and Mujica, in preparation), which is a relatively small figure if compared with the maximum of 40,000 eggs recorded for Spanish sardine.

The spawning area for common sardine is unknown (Serra, et al., 1979) and no ova have ever been found in the ichthyoplankton surveys carried out in the Central-Southern zone of Chile. This gives rise to the hypothesis that this species spawns on the bottom of the sea like its relative the herring does in the northern hemisphere. The greater concentrations of larvae in the area of Talcahuano (Gulf of Arauco, Bay of Concepción) suggest that this is the main spawning area.

Spanish sardine, like anchovy, spawn in two main areas, that is: the Northern Zone and Talcahuano (Fig. 13). The maximum extension to the west is 80 nautical miles. Studies carried out by IFOP in the 1964-1973 period, between Arica and Chile (42°S), do not record eggs and larvae of spanish sardine further South than 25°S. Balbontin and Garreton (1977) reported having found eggs of this species off Valparaíso in 1975. In figure 13 a comparison is made of the distribution of spanish sardine eggs collected in August for the 1963-1972 and 1981 period, which shows the changes that have occurred in the geographic distribution of spawning. In fact the spawning area of Talcahuano did not exist in the 1964-1973 period.

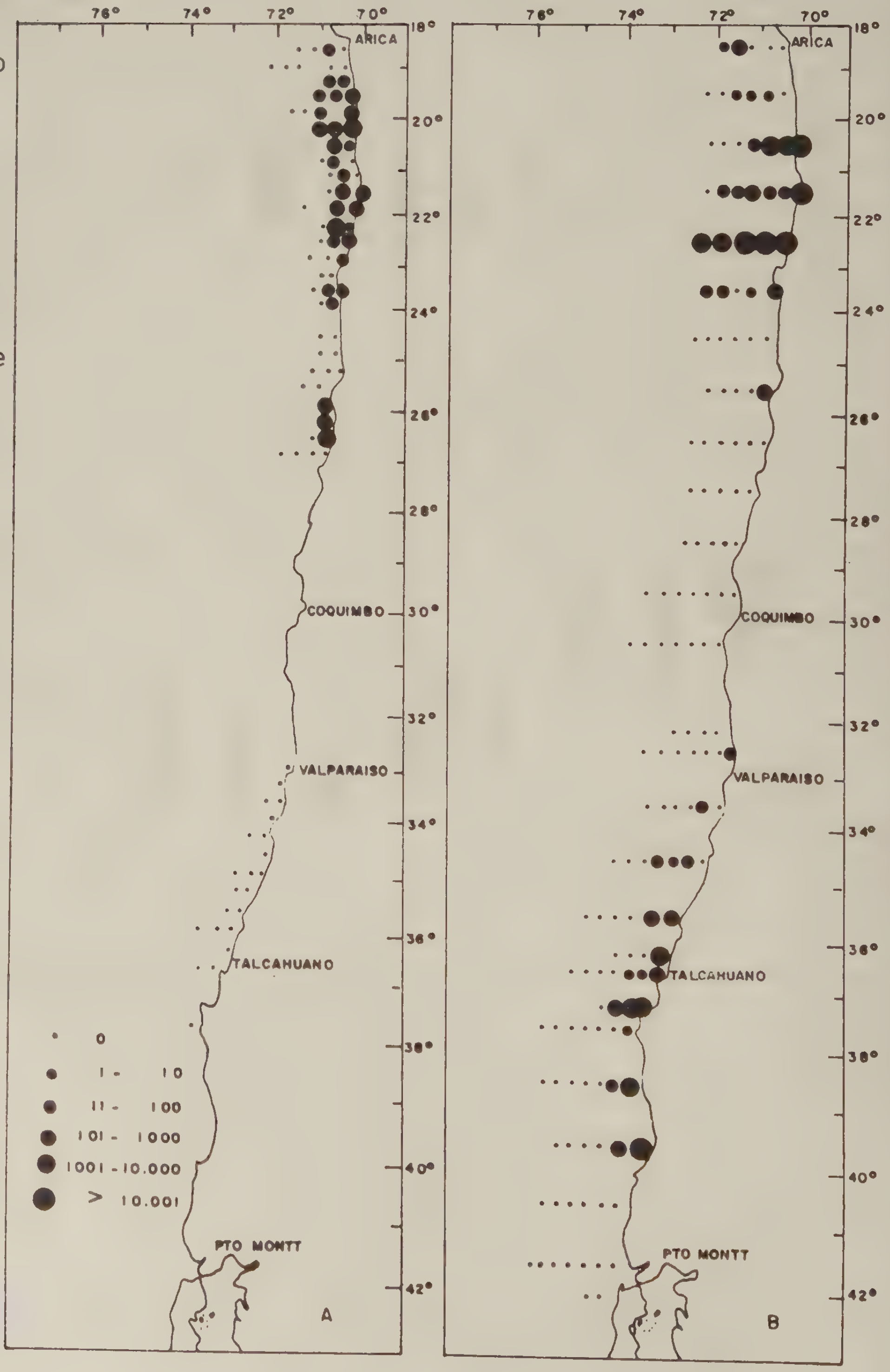

Fig. 13. Spawning area of the spanish sardine.
A. August 1963-1972
B. August 1981.
From O. Rojas, pers. com.

## GROWTH AND NATURAL DEATH RATE

Table 2 shows the parameters of the growth equation of Von Bertalanfly, maximum age observed in fisheries and the natural death rate.

Table 2: Instantaneous rate of total mortality of the Spanish sardine.

| Method/year | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|
| 1. Regression | 2.6530 | 1.8551 | 1.7575 | 1.8584 | 1.9966 |
| 2. S (Z) | 2.4232 | 1.8315 | 1.1555 | 1.6993 | 1.8328 |
| 3. Heincke | 2.0521 | 1.7166 | 0.7890 | 1.3244 | 1.4925 |
| 4. Robson and Chapman | 2.1436 | 1.7247 | 1.0321 | 1.4401 | 1.5670 |
| Average mortality | 2.3180 | 1.7820 | 1.1835 | 1.5806 | 1.7222 |
| Standard deviation | 0.2735 | 0.0715 | 0.4118 | 0.2427 | 0.2341 |

From Serra and Zuleta 1982.

The parameters for the Northern Zone and Talcahuano are shown below for jack mackerel. The maximum sizes of this species in the fisheries for fishmeal corresponds to samples of about 40 cm. fork length. In the sixties and beginning of the seventies there was a bonito and jack mackerel fishery in the northern zone for canning purposes; in this case jack mackerel of over 40 cm. fork length was caught as required by the factory. Maximum sizes exceeded 65 cm. fork lengths to a maximum of 72 cm. From the foregoing it may be concluded that the estimated K values for jack mackerel correspond to the fraction of the population which sustains the fishmeal industry. In order to obtain an approximate K value for the population, a new adjustment based on the Beverton method was made of the data on average length-age available for fish up to 11 years old and considering an arbitrary asymptotic length of 65 cm. fork length. The result obtained was K = 0.08, a value which is similar to that estimated for jack mackerel in California (K = 0.0935; Wine and Knaggs, 1975).

To estimate the natural death rate an empirical physiological equation proposed by Pauly (1980) was used. The results are shown in Table 3.

Table 3: Growth parameters, maximum age and natural mortality.

| Species | $L_\infty$ | K | $t_o$ | $T_{max}$ | M |
|---|---|---|---|---|---|
| Anchovy | 19.04 cm. | 0.73 | -0.647 | 4 años | 1.3 (17°C) |
| Mackerel | 44.62 cm. | 0.16 | -1.553 | 9 años | 0.3 (18°C) |
| Jack mackerel ZN* | 45.9 cm. | 0.167 | -0.882 | 11 años | 0.4 (18°C) |
| Jack mackerel T* | 44.3 cm. | 0.181 | -0.756 | 11 años | 0.4 (15°C) |
| Common sardine | 17.85 cm. | 0.45 | -0.828 | 4 años | 0.5 (13°C) |
| Spanish sardine | 42 cm. | o.19 | -0.8 | 11 años | 0.4 (18°C) |

* ZN = Zona Norte (Northern Zone); T = Talcahuano

## ABUNDANCE

Changes in abundance have been described using catches and catches per effort unit. Catches have been used on the assumption that there is a good correlation between the latter and stocks when the effort is high and there are no limitations to fishing volumes. The trend of catches for different species was already analyzed in the corresponding paragraph.

The catch per effort unit is the classical abundance index of fisheries studies. However, in recent years it has been determined that it is not a good index for the quantitative description of changes in pelagic fish stocks (Schaff, 1975; MacCall, 1976; Ulltang, 1976). Nevertheless, its consideration is useful to indicate the changes that have taken place, as may be seen in Figures 6, 9, 14 and 15, which represent a trend similar to that of catches (Fig. 2) for the different species. These changes were confirmed in the case of spanish sardine, for which an estimate of stocks was obtained expressed by the mean biomass, with data provided by virtual population analysis (Serra and Zuleta, 1982). The changes in the mean biomass are shown in Figure 16, where the increase in spanish sardine stocks from 1974 onwards with a similar pattern as that of catches per effort unit may be seen.

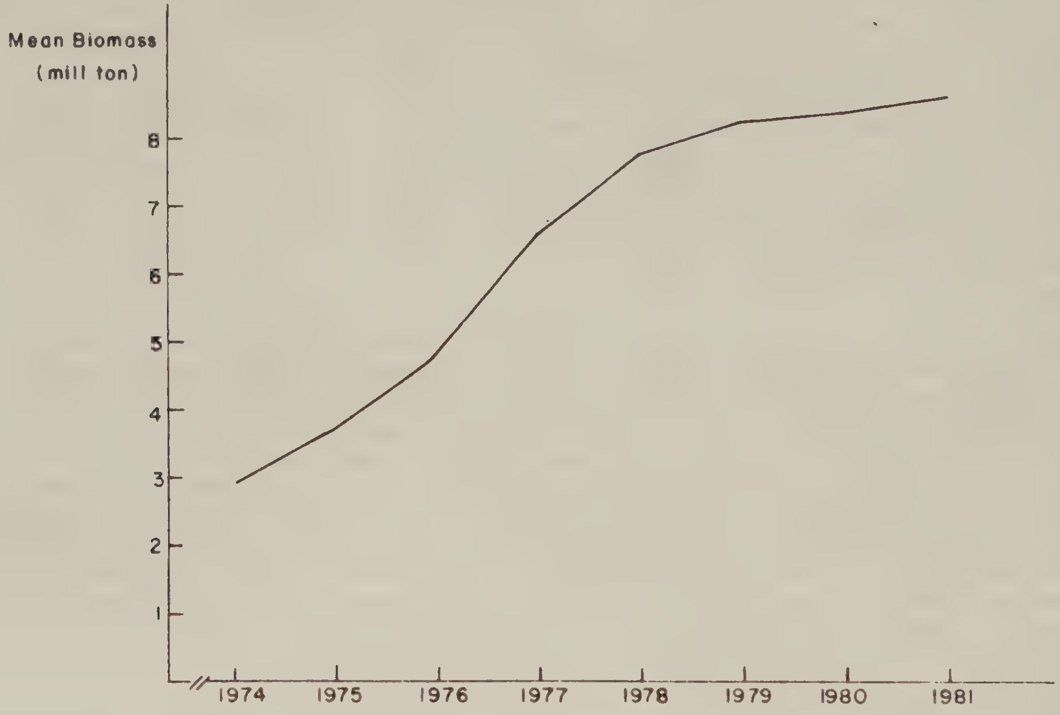

Fig. 16. Change in the mean biomass of the Chilean spanish sardine (1974-1981) estimated by VPA (from age 3). From Serra and Zuleta (1982).

At the same time that mackerel, jack mackerel and spanish sardine stocks were increasing, anchovy collapsed in the Northern Zone in 1977, its stocks having decreased substantially already in 1972 (Fig. 6), and of the mixed resource of common sardine and anchovy in Talcahuano in 1975-1976.

In accordance with the above catches and catches per effort unit are useful in describing the explosive growth phase of these resources qualitatively. However, their use is considered to be limited in describing their stabilization and decline.

There are estimates of spanish sardine stocks for recent years based on the hydro-acoustic method and on the virtual population analysis (Serra and Zuleta 1982). Estimates made with the hydro-acoustic method in the area from the border with Perū as far as 24$^{0}$ latitude South and 200 nautical miles, show a biomass of 5,500,000 and 5,100,000 tons in 1981 (June-July) and 1982 (July-August) respectively. The mean population biomass for the years 1974 to 1981 was obtained on the basis of virtual population analysis. Results indicate that spanish sardine stocks, age 3 and above, were at a level of 8,500,000 tons in 1980 and 1981, and around 8,000,000 tons in 1978 and 1979. The difference with the results obtained with the acoustic method is being analyzed.

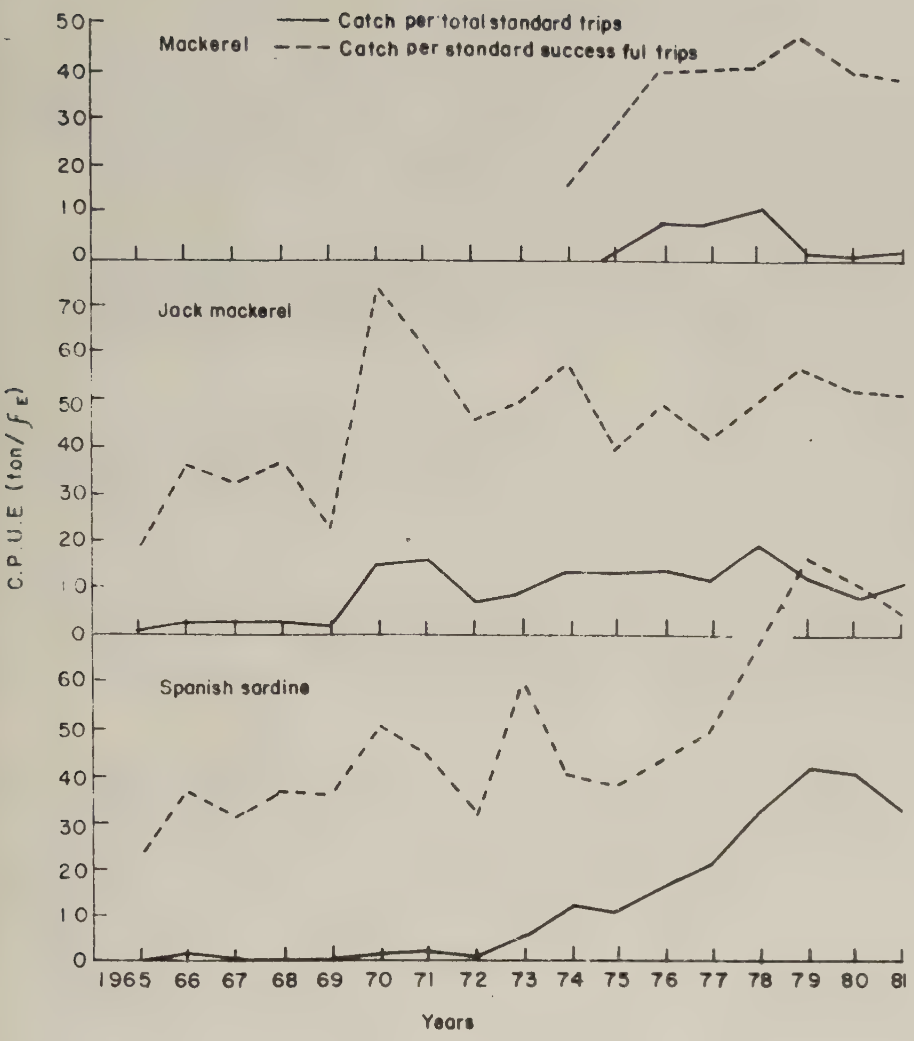

Fig. 14. CPUE of mackerel, jack mackerel and spanish sardine of Chilean pelagic fishery of the northern zone, 1965-1981.
From Serra (1981).

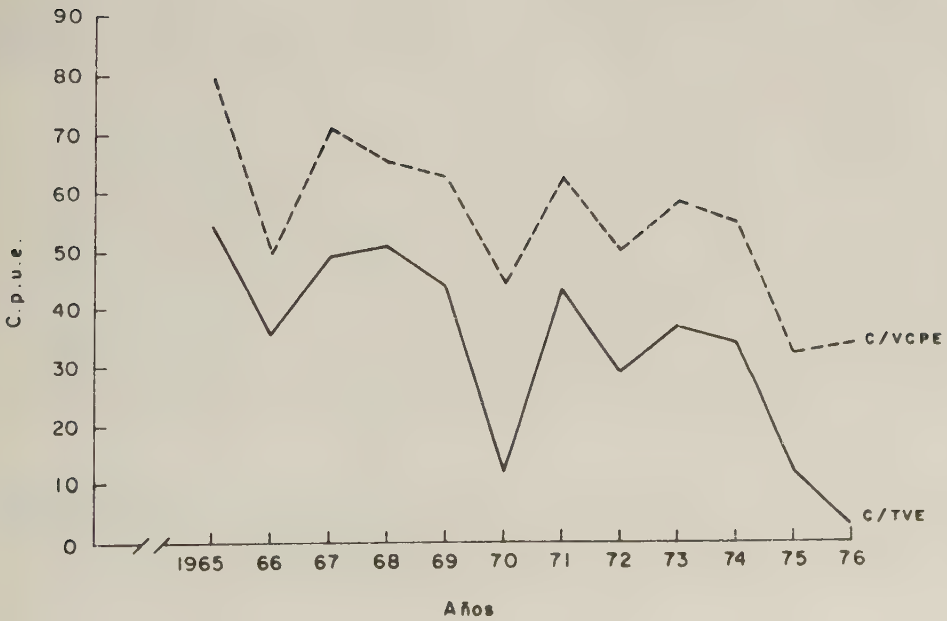

Fig. 15. Catch per unit effort of the anchovy-common sardine resource from Talcahuano.
C/VCPE = catch per standard trips with catch;
C/TVE = catch per total standard trips.
From Serra (1978).

## EXPLOITATION AND MANAGEMENT

Serra (1978; in press) applied the Schaefer model and the general production model of Pella and Tomlinson (m=2) to the data on catches and effort in mixed common sardine and anchovy fisheries in Talcahuano and anchovy in the Northern Zone respectively (Fig. 17 a; b). In both cases the models did not adjust, if the entire series of years was considered, which was finally achieved by eliminating the last years.

The explanation for this non-adjustment is that the catch-effort relation in both cases curves toward the origin. This happens mainly because the effort does not represent the fishing mortality rate, as the capturability coefficient (q) varies in an inverse proportion with abundance (Gulland, 1976).

A depensatory catch-effort curve was overlaid on the data for both fisheries (Fig. 17), from which it is possible to conclude that, without regulations, these fisheries come very close to the critical level defined by the depensatory catch-effort model when they reach their maximum catch levels. Any environmental disturbance or a greater fishing effort are enough to cause the resource to collapse.

From the above it may be concluded that the levels of exploitation reached in anchovy fisheries in the Northern Zone and in common sardine-anchovy in Talcahuano were too high, and this could explain the great fluctuations in catches (Fig. 2 and 3). The studies carried out by Serra (1978; in press) conclude that fishing cannot be disregarded as an important factor responsible for the collapse of these fisheries.

In spite of the accelerated development of these fisneries and their subsequent collapse, no regulatory measure was applied and mention can be made only of an effort of the Department of Fisheries and Game of the Ministry of Agriculture, responsible for fisheries management, to introduce a restriction on the size of anchovy in 1965, which finally did not prosper because it lacked a sound enough technical basis and the elements needed for its application. Later, during the 1972 and 1973 crisis caused by "El Niño" phenomenon, no regulatory measures were taken either, at least legally. However, there was an agreement between the Ministry of Fisheries of Perū and of Chile to establish a moratorium of one week on anchovy fisheries in the Northern Zone, if fish of less than 11.5 cm. exceeded 20% of the landings of fishing activities in the area between Ilo (Southern Perū) and Arica (Northern Chile). Concretely, this measure was never applied and the agreement lasted until 1973, when a change took place in the political regime of Chile. In addition, there were two military edicts, originated by the Regional Government and outside of the institutional framework of fisheries administration. The first one, in December 1973, established a one month moratorium for Arica and Iquique and the second, in December 1977, prohibited industrial fisheries in the coastal areas of Iquique, for the purpose of avoiding conflicts between artisanal and industrial fishermen.

In 1981 an analysis was made to determine the state of pelagic resources in the Northern Zone (SUBPES), 1981; Serra, 1981), for which all information available was taken into account, such as patterns of landing curves in similar fisheries, catch per effort unit, modal sizes, depensatory model of catch-effort and exploitation rate in the case of the spanish sardine, the only species for which the age structure of the landings was known. All of this information was integrated to make a diagnosis of fisheries. The situation of the fishery was considered to be of great risk on the one hand, catches were increasing too rapidly, especially those of spanish sardine, mackerel catches decreased, the growth of catches per effort unit stopped, modal sizes of spanish sardine and jack mackerel decreased; and on the other because of the absolute ignorance regarding the recruitment strength.

In the case of spanish sardine an exploitation rate of 43% was estimated, which was excessive in accordance with the criterion defined as the adequate level of exploitation, that is when F=M, and is the result of empirical evidence provided by the analysis of various similar fisheries in the world (Troadec, Clark and Gulland, 1980).

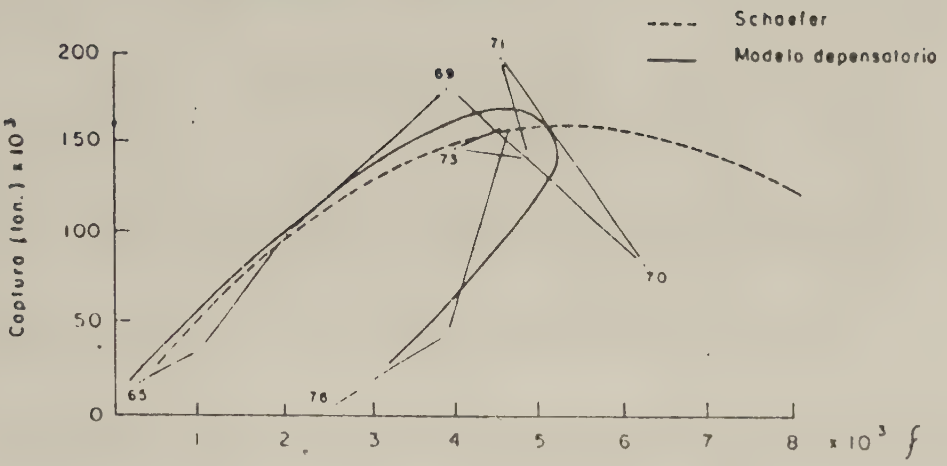

Fig 17a. Catch-effort curve of the anchovy-common sardine of Talcahunao.
From Serra (1978). Depensatory curve fitted by hand.

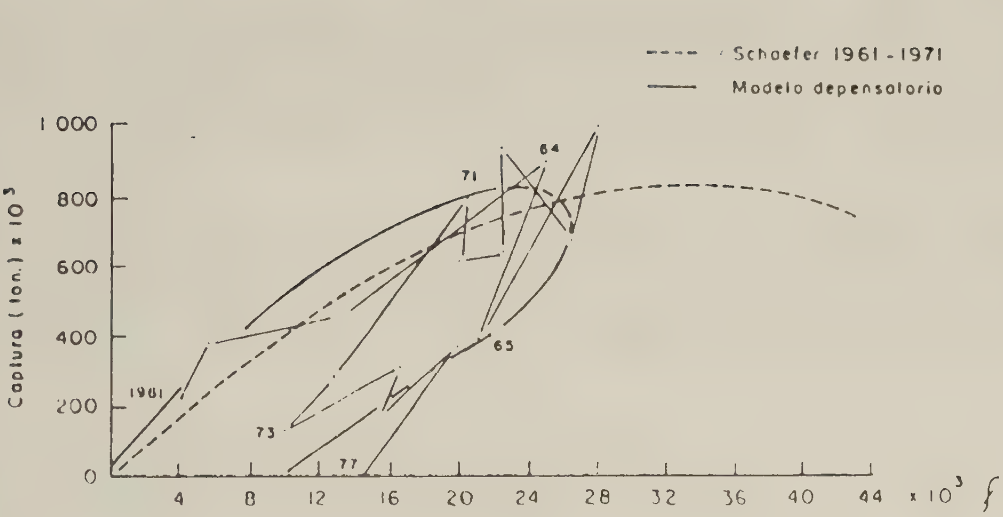

Fig. 17b. Catch-effort curve of the Zona Norte anchovy fishery.
From Serra (in press). Depensatory curve fitted by hand.

When considering this situation, the Under-Secretariat of Fisheries concluded that it was necessary to adopt management measures, to decrease the exploitation rate of the resources and increase their probability of permanence at satisfactory levels of abundance for fisheries activities.

In accordance with the above three regulations were adopted:

a) Fixation of a minimum size for spanish sardine (20 cm. total length) and jack mackerel (26 cm. fork length).

   The minimum size was estimated on the base of the criterion of critical age, to make a more efficient use of the growth of the species (overfishing by growth) at the same time increasing the expectation of an individual to reach adulthood (Decree Law No. 458).

b) Prohibition of the use of purse-seines with nets over 20 fathoms deep and a mesh size equal to or less than 38 mm., along a coastal fringe of one nautical mile (Decree Law No. 459).

   Knowledge on the spacial distribution of anchovy, mackerel and spanish sardine indicates that their breeding areas lie along the coastal fringe. Thus, the recruiting force is protected.

c) Determination of a quota of allowable catches for spanish sardine in the northern zone for 1982.

   The allowable catch quota was calculated using the catch equation of Boranov and assuming that the biomass existing in 1982 was the same as in 1981.

   First a projection was made of spanish sardine catches for 1981, based on available data up to September of that year and on seasonal patterns observed during 1978, 1979 and 1980.

   Then a 39% exploitation rate was established as a gradual approximation to the adequate level of 30%, which results when F=M and M=0.4. The quota calculated was of 1,300,000 tons.

Finally, it is necessary to explain that the application of an allowable catch quota caused conflicts because it was completed before the end of the period for which it had been established. Consequently, the quota was supplemented with 116,000 tons (Decree Law No. 263), which represents the establishment of a 42% exploitation rate, in accordance with the estimates made. This supplement was also completed before the end of the fishing season.

Fishing entrepreneurs started negotiations with the authorities in connection with the socio-economic problem that would originate if spanish sardine fisheries were stopped. This situation, which was aggravated by a severe recession in the national economy, presented the authorities with the dilemma of favouring the activity or applying the regulation. The first alternative was chosen, finally increasing the catch of spanish sardine in the northern zone to 1,650,000 tons in 1982.

During 1982, with a longer series of years (1974 to 1981) with an age structure, new estimates were obtained on the total instantaneous mortality rate (Z) and on fishing rate (F) (Serra and Zuleta, 1982). The results (Tables 2 and 4) confirmed the analysis made in 1981 (Serra op. cit.), in the sense that the values of Z and F are too high for the fraction of population recruited into the fishery, age 7 and above. The new results obtained are even higher than those of 1981, the exploitation rate increasing up to levels of 70% for some years.

Table 4: Instantaneous rate of fishing mortality of the spanish sardine.

| | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.00024 | 0.00001 | 0.00002 | 0.00011 | 0.00751 | 0.00000 | 0.00023 | 0.00050 |
| 4 | 0.00411 | 0.00018 | 0.00038 | 0.00052 | 0.00678 | 0.01485 | 0.00787 | 0.00900 |
| 5 | 0.07645 | 0.01386 | 0.00846 | 0.01144 | 0.02218 | 0.12036 | 0.14108 | 0.13000 |
| 6 | 0.32767 | 0.13629 | 0.04695 | 0.12513 | 0.11698 | 0.42851 | 0.57233 | 0.42000 |
| 7 | 0.94997 | 0.38887 | 0.23893 | 0.41998 | 0.36970 | 0.96075 | 0.91837 | 1.10000 |
| 8 | 1.65367 | 1.02590 | 0.38641 | 0.91470 | 0.92693 | 2.08525 | 1.33174 | 1.37000 |
| 9 | 3.20798 | 1.65268 | 1.02813 | 1.07590 | 1.45110 | 3.24382 | 2.13925 | 2.34000 |
| 10 | 2.60000 | 2.60000 | 2.60000 | 2.60000 | 2.60000 | 2.60000 | 2.60000 | 2.60000 |
| 3+ | 0.03706 | 0.01924 | 0.01515 | 0.03999 | 0.04959 | 0.24315 | 0.13959 | 0.12800 |

From Serra and Zuleta (1982) with VPA.

However, on the other hand virtual population analysis provides optimistic prospects due to abundance of the resource and because no decrease is evident in the strength of the year classes that are entering the fishery (Table 5).

Table 5: Mean biomass for each age group of the spanish sardine.

| | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 |
|---|---|---|---|---|---|---|---|---|
| 3 | 1163670 | 1203520 | 1660080 | 2563420 | 2326160 | 2349410 | 2420170 | 2566370 |
| 4 | 1032600 | 1137300 | 1176130 | 1622190 | 2497610 | 2248920 | 2287930 | 2355600 |
| 5 | 522397 | 909793 | 1004560 | 1037420 | 1423740 | 2087530 | 1853980 | 1902760 |
| 6 | 157316 | 390724 | 733148 | 783198 | 810543 | 963018 | 1259630 | 1180390 |
| 7 | 37366 | 87322 | 257537 | 468352 | 490216 | 399213 | 405600 | 455387 |
| 8 | 9659 | 10718 | 45260 | 116629 | 190721 | 136823 | 101475 | 104341 |
| 9 | 1723 | 1375 | 2855 | 17266 | 28444 | 27097 | 12437 | 14313 |
| 10 | 389 | 60 | 143 | 443 | 2600 | 3378 | 913 | 932 |
| 3+ | 2925130 | 3740810 | 4879710 | 6608920 | 7770040 | 8215390 | 8342140 | 8580100 |

From Serra and Zuleta (1982) with VPA.

Preliminary data on the stock-recruit relationship (Fig. 18) indicate that recruitment has been independent (nearly constant) of the size of the stock for the points considered, but this also means that the number of recruits per spawning fish has decreased together with the growth of the parent stock.

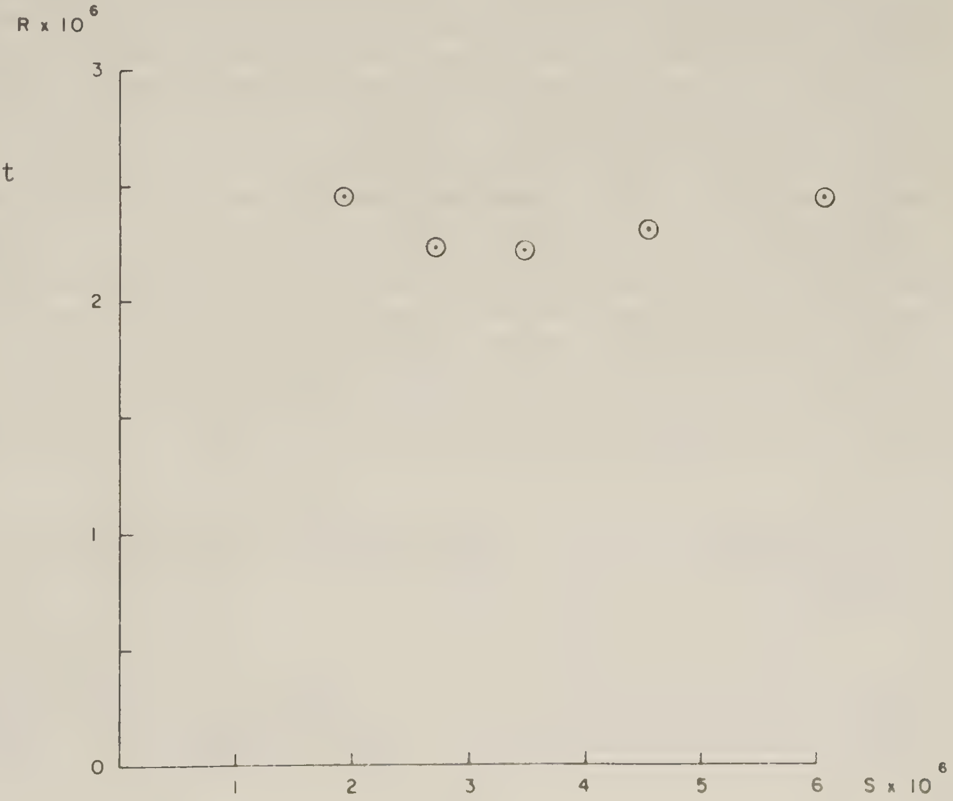

Fig. 18. Stock-recruit relationship of the spanish sardine.

# DISCUSSION

The above shows very clearly the drastic changes that have taken place in Chilean pelagic fisheries. After the collapse of the anchovy and of the common sardine-anchovy resources in the northern zone and Talcahuano respectively, there was an unexpected and fortunate increase in spanish sardine, jack mackerel and mackerel stocks. Fisheries in the northern zone changed from a practically mono-specific system, in which anchovy dominated, to a multi-specific system with the dominance of spanish sardine. In Talcahuano the system changed from the dominance of the mixed common sardine-anchovy resource to that of jack mackerel. It is possible that in both cases it would be more appropriate to speak of succession or successional fisheries instead of multi-specific fisheries.

It is important to point out that after the changes in dominance in both fisheries, total yields reached maximum levels a little over twice as much as those reached in the previous systems, for which there is no clear explanation.

Simultaneously with the change in the abundance of the species, a change took place in their geographic distribution and in the size of the spawning areas. The most spectacular case is probably that of spanish sardine, this species "colonized" (Kondo, 1980; Sharp, 1980), the area toward the south which it invaded, and even established a new spawning area. It is interesting to note that here also the association of abundance and spatial distribution in this type of resource was effected.

Data provided by Santander and Castillo (1979), Santander (1981), Tsukayama (1982) show similar changes in Perū.

The five species analyzed have similar natural history patterns; they are all iteroparous reproducers and their parameters of longevity, growth and age at first maturity form a consistent pattern (Tables 1 and 2), in agreement with what has been established by Beverton (1963). However, differences may be observed in the spatial patterns of spawning, mainly between clupeids (anchovy and spanish sardine) and jack mackerel. The first have defined spawning areas (Fig. 10 and 13), with focal points with high densities of eggs. As many as 40,000 eggs per 10 square meters having been reported for spanish sardine. Jack mackerel, on the other hand, has a more dispersed pattern (Fig. 12), reproductive products being distributed over a far greater area. The maximum density recorded is of 2,400 eggs per 10 square meters. Curiously, the growth rate of jack mackerel at the embryo and larva level is the slowest of the genera represented (Theilacker and Dorsey, 1980). If the spawning area of jack mackerel spreads from 24°S as far as 40°S and from the coast well beyond 200 nautical miles, and so far great concentrations of eggs and larvae have not been clearly identified; is it possible to define what conditions are the most suitable for the survival of embryos and larvae, and to know the requirements of density of food particles and conditions associated with the stability of the ocean. Bakkun and Parrish (1982) determined that the area in which jack mackerel spawns is highly turbulent and has strong Ekman transport. Contrarily, anchovy, spanish sardine and mackerel, have their main spawning grounds between the border with Perū (Arica) and Antofagasta, an area which has been described to have great ocean stability (Bakkun and Parrish, 1982), in the terms of Lasker (1981). The second most important spawning ground of anchovy, spanish sardine and also the most likely spawning ground of common sardine, is the area of Talcahuano (37°S) where spawning takes place close to the coast, protected by gulfs and bays from the more unfavourable conditions away from the coast where jack mackerel spawns (Fig. 12). It is even postulated as a hypothesis that common sardine spawns on the bottom of the sea.

It may be concluded from the foregoing that all these species present a fractioned spawning pattern, in batches, with relatively large reproductive periods, and an exploratory reproductive behaviour of the habitat in time and space due to the variability and unpredictability of climatic conditions.

In spite of environmental variability, clupeids and probably mackerel, concentrate their spawning in the more favourable areas which are those of greater stability, and jack mackerel, on the other hand, seeks areas which appear to be more unfavourable, in accordance with existing knowledge, where it disperses its reproductive material.

The behaviour of the adult jack mackerel population which is scarcely represented in the fishery, is concordant with this spawning pattern. It may be concluded from the information on distribution of this species, its spawning pattern and the size structure in the landings, that this fishery is sustained only by a sector of the population, that is, mainly by individuals between 26 and 34 cm. fork length (4 to 8 years of age). Projecting age studies on *T. symmetricus* carried out in California, 70 cm. fork length individuals are over 25 years old (MacCall, et al., 1980). The missing fraction of the adult stock, changes its behaviour, and apparently migrates to the high seas (catches by Soviet ships) and probably also disperse forming small schools (large jack mackerel caught by artisanal fishermen and by a small fleet of bonito boats at the beginning of the seventies). In this sense the characteristics of this fraction of the population is its dispersion, which is consistent with the spread of the geographic area observed in connection with the spawning grounds, which is not explained by the phenomenon of egg diffusion.

It may be concluded from available data that exploitation levels of anchovy in the northern zone and of common sardine-anchovy in the Talcahuano area were too high, in accordance with present knowledge on pelagic resources. In this regard, it is not possible to blame only environmental changes for the collapse of these resources, fishing also being responsible. Nevertheless, it is surprising to notice that when these resources are in the phase of stock growth they can support high fishing rates, as those observed from 1974 onwards in the case of spanish sardine from the age of 7, this being the age group in which this species is totally recruited in the fishery (Table 4), no apparent negative effects to their expansion having been observed.

The history of these fisheries does appear to indicate however, that the combination of a high exploitation rate with adverse environmental conditions is extremely dangerous to the maintenance of adequate stock levels for fisheries.

## ACKNOWLEDGEMENT

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*EASTERN CENTRAL ATLANTIC - ATLANTICO CENTRO-ORIENTAL*

# THE INFLUENCE OF HYDROCLIMATIC FACTORS ON THE AVAILABILITY OF THE SARDINE (*Sardina pilchardus* Walbaum) IN THE MOROCCAN ATLANTIC FISHERY

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## Resumen

La sardina es la especie dominante en la pesquería nerítica del Noroeste de Africa. Se han identificado tres unidades de stock, las que probablemente tienen algún grado de mezcla, y hay tres tipos de pesquerías que se han desarrollado después de la última guerra mundial.

La pesquería de marruecos es la que se encuentra más hacia el norte y es la que se encuentra expuesta a las variaciones más amplias en la disponibilidad de los recursos, lo que afecta la explotación por parte de los barcos artesanales con redes de cerco que tienen un reducido radio de acción. La disponibilidad está influenciada por las variaciones de la intensidad de los afloramientos, los que en verano provocan una migración trófica de la sardina del sur hacia el norte.

Al haber revisado la información disponible sobre el sistema de afloramientos en la corriente de Canarias y sus efectos sobre la productividad biólogica, los autores ponen en evidencia la influencia de los factores climáticos como las lluvias y la intensidad de los vientos alisios sobre la producción. Las capturas más importantes se obtienen en años de fuerte sequía, los que parecen ocurrir en ciclos de siete a ocho años. El análisis de la velocidad del viento en el centro del área donde se desarrollan las pesquerías muestra una disminución progresiva en los últimos veinte años, la que se hace más significativa desde 1975; esto ha afectado el volumen y composición de las capturas. La variabilidad del viento parece tener tanta importancia como su velocidad promedio en el proceso de productividad biológica de la región.

La disminución de la captura por unidad de esfuerzo de la flota de marruecos no es proporcional con la evolución de la abundancia de los stocks. Si la tendencia a la disminución de los vientos alisios continúa en el futuro, la disponibilidad de sardina en las zonas de pesca tradicionales continuará a disminuir y el patrón de la explotación de este recurso tendrá que ser completamente modificado para permitir una mayor utilización de la caballa y para tomar en cuenta el desplazamiento de la pesquería de sardina hacia el sur.

Los autores también han analizado las variaciones en la biomasa y las capturas observadas al sur del área en las otras pesquerías, en función a los datos sobre la intensidad de los afloramientos disponibles. No se puede explicar una relación aparente entre las capturas en la pesquería central y la intensidad promedio del afloramiento durante los últimos tres años en base a un incremento del tamaño de la población, ya que no se ha podido demostrar ninguna relación entre el reclutamiento y el afloramiento. Por el contrario, en la pesquería del sur, que es la más reciente, la biomasa y las capturas han aumentado considerablemente a continuación de un aumento del afloramiento, y luego han disminuido cuando la fuerza de afloramiento volvió al nivel promedio de los años precedentes. La abundancia de este stock está estrechamente correlacionado con la intensidad del desove en los dos o tres últimos años.

# INTRODUCTION

## GEOGRAPHICAL SITUATION WITH RESPECT TO STOCKS AND DESCRIPTION OF FISHERIES

### Geographical Situation

The sardine (*Sardina pilchardus* Walbaum) is found in west African Atlantic coastal waters from the Strait of Gibraltar (36°N) to Cape Blanc in Mauritania (21°N), where it is the principal small pelagic resource (Figure 1).

Surveys of exploration and acoustic evaluation undertaken between 1973 and 1982 have shown that the distribution of the sardine is not homogeneous (Villegas and Goodlad 1974; Lamboeuf 1974, 1977; Johannesson et al., 1975; Bazigos et al., 1980; Lamboeuf et al., 1981; Lamboeuf et al., 1982).

This heterogeneity has given rise to different fisheries which have been described several times by different authors (Belvèze 1972; Krzeptowski 1975, 1978; Bravo de Laguna et al., 1976; Barkova 1976; Belvèze and Bravo de Laguna, 1980).

There exist a number of studies on biometric and meristic characteristics (number of vertebrae, number of branchiospines), of growth curves and of biochemical composition (protein electrophoresis of the eye lens) (Furnestin 1950, 1955; Cadenat and Moal, 1955; Moal 1957; Rodriguez-Roda 1958; Andreu 1969; Belvèze 1971; Maigret 1974; Krzeptowski 1975; Bravo de Laguna et al., 1976; Barkova and Domanevsky, 1976; Belvèze and Rami, 1978; Biaz 1978; Barkova 1976; Fernandez et al., 1978; Freon and Stéquert, 1979).

Studies of these areas and periods of reproduction have also been published (Furnestin and Furnestin, 1959; 1970; Barkova 1976; Rubies and Palomera, 1977; Sedletskaya 1973).

Although at times contradictory, these observations have lead the Ad hoc Working Group on the Sardine of the Committee for East Central Atlantic Fisheries (CECAF) to identify three population units from north to south. However, it is probable that there is a certain amount of mixing between these stocks at their borders during the seasonal migrations, as pointed out by Bravo de Laguna et al. (1976) and Fernandez et al. (1978).

These population units are situated between 36°N and 33°30'N, 32°30'N and 27°N, and 26°N and 21°N (Figure 2). Their relative importance varies with time. The northernmost population is always the smallest.

### Description of Fisheries

The sardine fishery developed progressively from the north to the south during the last forty years. The start of the exploitation goes back to the 1930's, taking place from existing ports: El Jadida, Casablanca, Mohammedia and Larache, and concerned only the small northern stock.

After World War II, fishing started between 32°30'N and 30°N from the ports of Safi, Essaouira and Agadir, which now account for about 90% of the Moroccan sardine catch. The catch is taken by a fleet of 230 to 250 artisanal, wooden seiners of small size. Average gross tonnage increases regularly, passing from 35 tons in 1970 to 52 tons in 1981. The fleet is not homogeneous, with sizes varying from 15 to 120 tons.

The sardine boats put their catches into the holds without any means of preservation on board. Thus, the extent of the fishing area is limited by the rate of decomposition of the fish. The time spent at sea does not exceed twelve hours, which corresponds to a maximum distance from the home port of approximately 40 nautical miles. This limitation of fishing area does not allow the fishermen to follow the movements of the sardines and therefore, this fishery is gravely affected by the availability of fish within the zone of action. This results in important fluctuations in landings from one season to another and from one year to the next. This fishery, which exploits only the northern part of the population living between 32°30'N and 27°N, has been named fishery A by the Working Group on the Sardine of CECAF, and we will use this terminology in this paper.

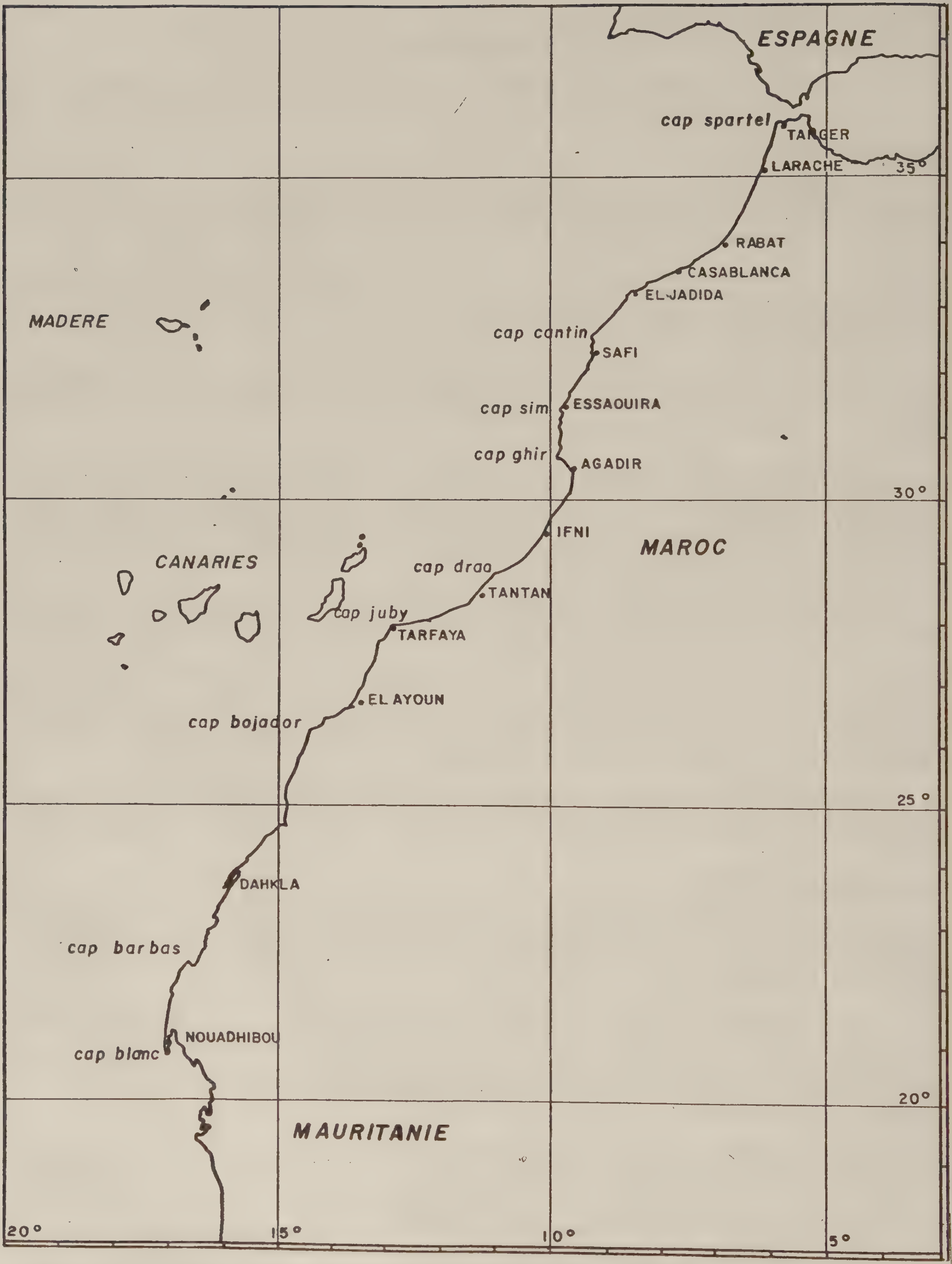

ESPAGNE
cap spartel
TANGER
LARACHE
35°
RABAT
CASABLANCA
EL-JADIDA
MADERE
cap cantin
SAFI
cap sim
ESSAOUIRA
cap ghir
AGADIR
30°
IFNI
MAROC
CANARIES
cap draa
TANTAN
cap juby
TARFAYA
EL AYOUN
cap bojador
25 °
DAHKLA
cap barbas
NOUADHIBOU
cap blanc
20°
MAURITANIE
20°
15°
10°
5°

Figure Nº 1: Geographical situation of the Northwest African coast and the names of localities or capes mentioned in the text.

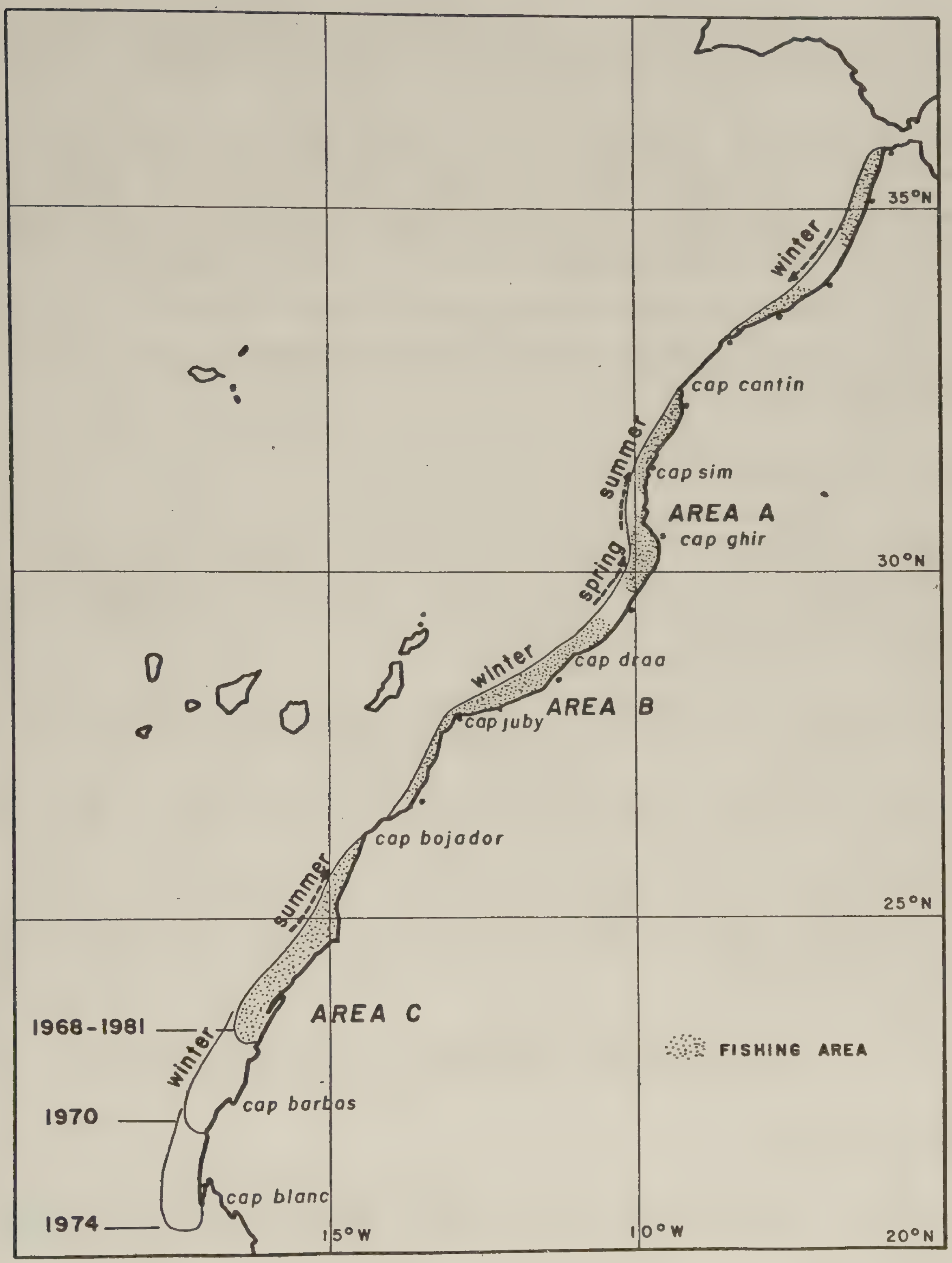

35°N
winter
cap cantin
summer
cap sim
AREA A
cap ghir
30°N
spring
winter
cap draa
cap juby
AREA B
cap bojador
summer
25°N
AREA C
1968-1981
winter
FISHING AREA
1970
cap barbas
cap blanc
1974
15°W
10°W
20°N

Figure Nº 2: Areas populated by the sardine, fishing areas and diagram of seasonal migrations along the Northwest African coast.

The by-catch of the seiners is composed of mackerel (*Scomber colias*), horse mackerel (*Trachurus trachurus*), anchovy (*Engraulis encrasicolus*) and more episodically, of trumpet fish (*Macrorhamphosus sp.*). However, the sardine is largely the predominant species.

Since 1965, a second fishery has developed for the southern part of the stock, between 29°N and 27°N. The boats are artisanal seiners based in the Canary Islands ports, about 100 nautical miles from the African coast. Numbering about 40, their size has been increasing for several years. Mean gross tonnage has grown from 130 tons in 1976 to 190 tons in 1980. Equipped with refrigeration or freezing systems, they can stay at sea until their holds are full. Their sphere of action and their mobility allow them to follow the movements of the sardine and to exploit year-round the zones of greatest concentrations.

This fishery has been named Fishery B by the CECAF Working Group on the Sardine.

Other boats have exploited or are still exploiting fishery B, either from Moroccan ports or from distant ports, but their catches are very small compared to the Canary Islands based boats.

There is little information on the accessory catches, but it appears that the sardine is the dominant species.

More recently, a fishery has developed based on the sardine to the south of the 26th parallel. Fishing is carried out by large pelagic trawlers, semi-pelagic trawlers and seiners associated with factory ships. Starting in 1969, this fishery has grown rapidly. The development of this fishery appears to be linked to a rapid increase in the sardine stock, followed by a geographical movement to the south after several massive spawnings, and intensified productivity in this region (Holzlohner 1975; Krzeptowski 1975, 1978; Domanevsky and Barkova, 1981).

Catch statistics are available for fisheries A, B and C (Statistical Bulletins of the CECAF, Reports of the Working Group on the Sardine of the CECAF). Catches for each fishing zone from 1965 to 1981 are presented in Figure 3.

Catches from zone A have varied around an average of 160,000 tons. Peak catches have been made in 1966, 1973 and 1983, with 1977 and 1978 having the lowest catches.

In zone B, catches increased regularly from 1965 to 1975, stabilized at around 120,000 tons from 1975 to 1978, and then diminished to 90,000 tons.

Zone C has experienced an extraordinary growth in catches, with an increase from 90,000 tons to 650,000 tons (1976) in six years, followed by a drop to 200,000 tons in three years.

## GENERAL HYDROCLIMATIC CHARACTERISTICS OF THE AREA AND REVIEW OF LITERATURE ON THE CANARY CURRENT UPWELLING SYSTEM

### General Climatology

The African Atlantic coast between the Strait of Gibraltar (36°N) and Senegal (15°N) is backed by a region which is, to a large extent, desert or sub-desert in character. In the middle of this area is the subtropical high pressure belt which is made up of two different units:

- The Atlantic anticyclone (anticyclone of the Azores) which is variable, in absolute value and in geographical position. To a large extent, it governs the Moroccan climate.
- The high altitude Saharan anticyclone, which is much more stable and which gives rise to a thermal depression.

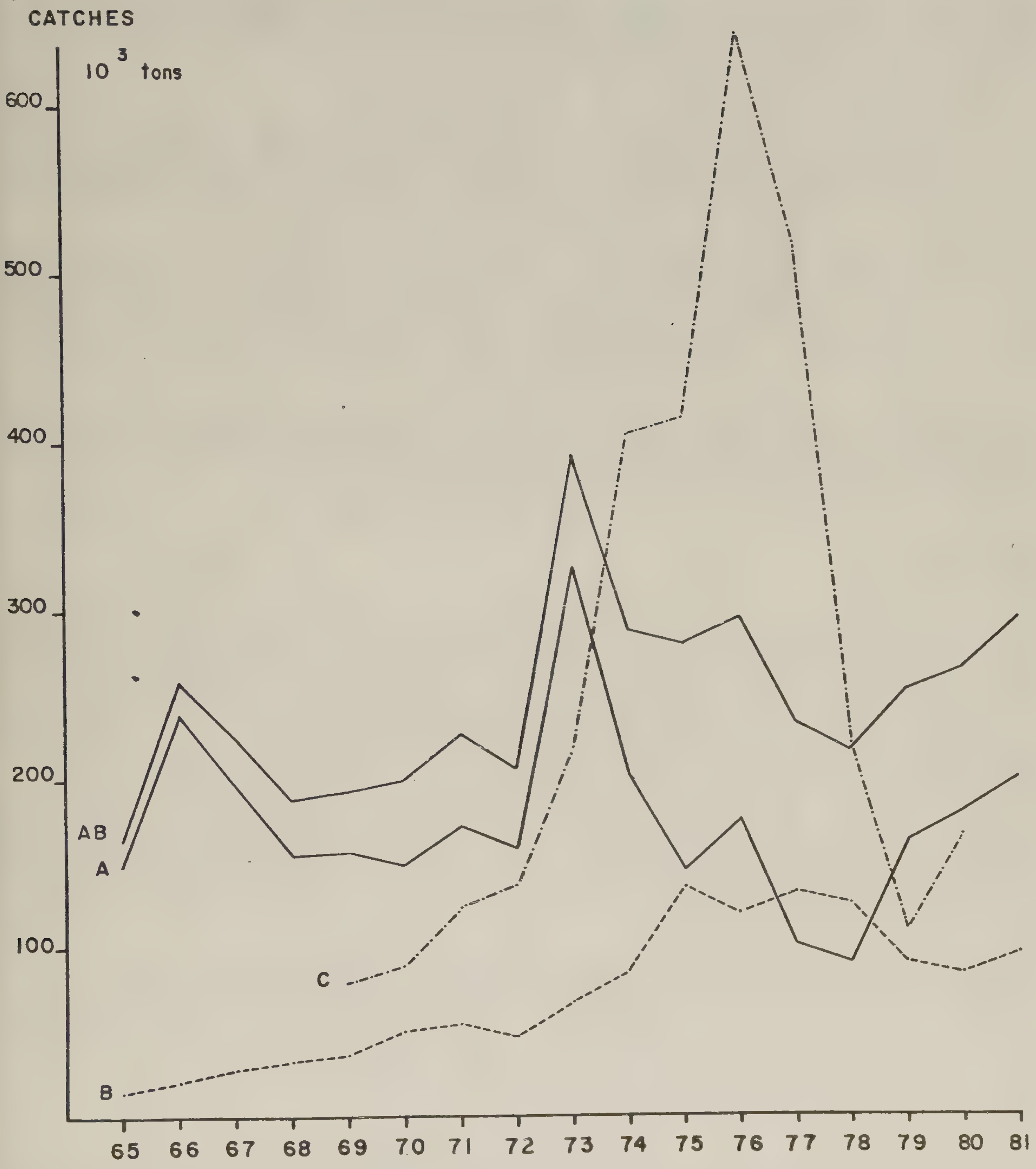


Figure N? 3: Catches of sardines in the different fisheries of the Northwest African coast from 1965 to 1981, in thousands of tons.

Between these two units, there is a quasi-stationary boundary between air of polar origin which circles the Atlantic anticyclone on the eastern side and tropical air from the southwest, which rises over the Saharan anticyclone. This boundary is sometimes called the trade wind front (Calvet and Le Goff, 1977).

Schematically, we can identify two seasonal situations;

-- The summer situation (Figure 4): The Atlantic anticyclone, centered in the neighbourhood of the Azores (38°N latitude) is strong (1035 mb), and drives the oceanic perturbations to northern Europe. A system of north to northeasterly winds (trade winds) is set up along the coast from 36°N to 20°N.

-- The winter situation (Figure 5): The anticyclone has descended to the west of the Canary Islands (25°N latitude) and has weakened (1025 mb). This permits the passage of a depression extending from Greenland to North Africa. This gives rise to west and southwesterly winds, which bring rain to Morocco north of 28°-30°N latitude. The trade winds are thus to the south of the Canary Islands, affecting the coastal region between 26°N and 15°N.

The result is a seasonal balancing of the trade winds, which originate off Gibraltar in the summer and more to the south in winter (LeFloch 1974). The position and strength of the anticyclone of the Azores governs the wind system along the northwest African coast as well as the rainfall of the northern half of Morocco.

## General Hydrology

From the Strait of Gibraltar (36°N) to Cape Blanc in Mauritania (21°N, the African coast is oriented more or less from northeast to southwest, with a succession of concave and convex parts determining capes (Figure 1). The trade winds, blowing from north/northeast are thus approximately parallel to the coast. The general sea surface circulation in this region is linked to the Canary Current. This northeast to southwest movement transports relatively cold waters along the northwest African coast (LeFloch 1974). The combination of this movement of water towards the south and the effects of the trade winds cause the upwelling of deep waters towards the surface. The upwelling varies in time and space as a function of bottom and coastal topography and the seasonal character of the trade winds. The origin of the upwelled water is at an average depth of 200 m. The temperature may be less than 16°C and the salinity, lower than that of oceanic surface waters, may reach a minimum of 35.7%, especially in the Cape Blanc area, where the North Atlantic waters of the Canary Current mix with the waters of lesser salinity from the south (Fraga 1974).

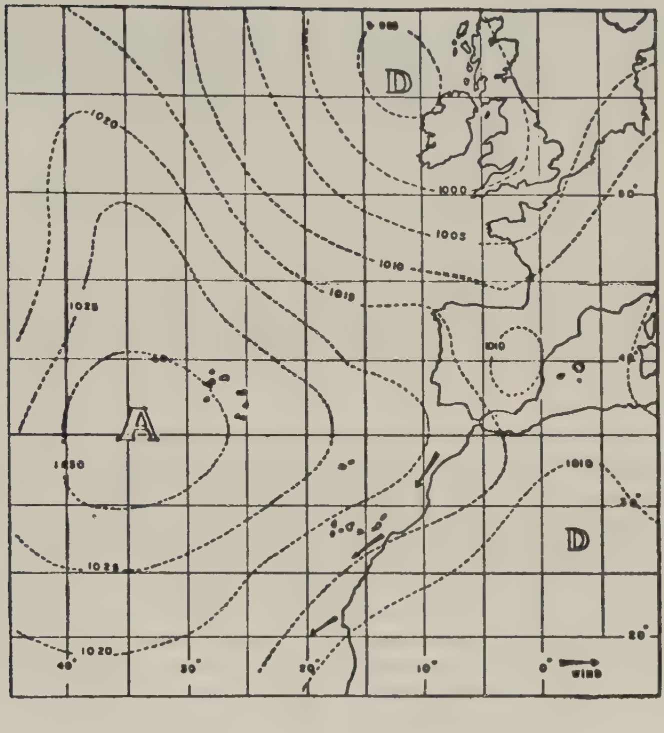
The emergence of these nutrient-rich waters in the euphotic zone results in the increased primary and secondary production characteristic of upwelling regions.

The existence, nature and mechanisms of these phenomena along the northwest African coast have been studied by many scientists in the past forty years.

## Brief Review of Studies on the Canary Current Upwelling

The Canary Current was described by studies of Prince Albert I of Monaco at the turn of the 19th century. Rouch (1931, 1948) explained the relatively low temperature of the current not only by the northern origin of the waters but also by the upward movement of deeper water taking place along the coast. Roux (1937) also attempted to describe the movement of the Atlantic water off Morocco by the theory of transgressions proposed by LeDanois in 1921.

It was the work of J. Furnestin from 1947 to 1953 which was the first to describe in detail the hydrology between the Strait of Gibraltar (36°N) and Cape Juby (28°N), and which gave evidence of the seasonal and regional character of the upwelling (Furnestin 1950 and 1959). Seven-year temperature averages allowed Furnestin (1959) to make trimesterly isotherm charts which show the principal characteristics of the system in


D
1000
1005
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1015
1020
1025
A
1030
1010
D
1020
40°
30°
20°
10°
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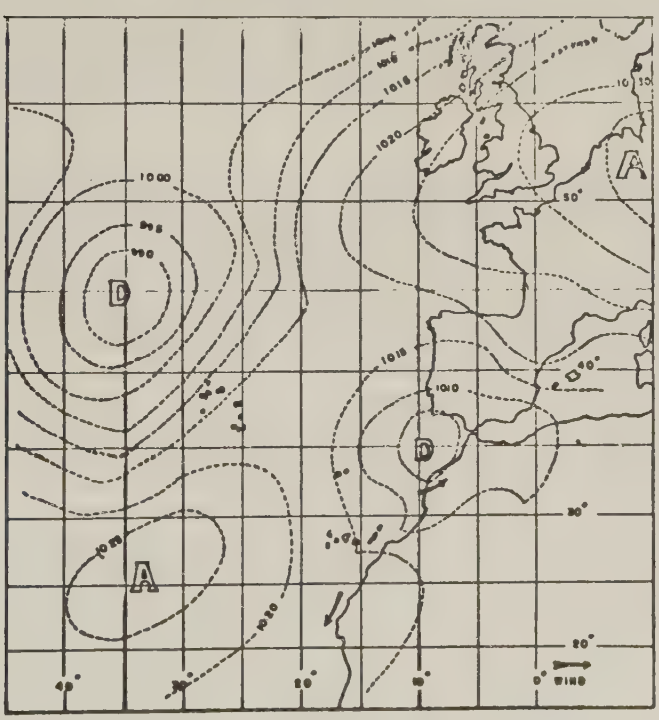
WIND
50°
30°
20°

Figure Nº 4: Typical summer climatic conditions bringing about Trade Winds on the Moroccan coast.


1015
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WIND
50°
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30°
20°

Figure Nº 5; Typical winter climatic conditions bringing about winds from the southwest and rainfall on the Moroccan coast.

the area of study. The upwelling, feeble or non-existent in winter, develops in spring, grows stronger in the summer and declines in fall in the coastal sectors between Safi and Cape Ghir, and between Ifni and Cape Juby. A small upwelling is found in the summer at the opening of the Strait of Gibraltar. Between these areas of active upwelling, the offshore waters, warmer and of higher salinity, may reach the coast, covering over the upwelled water and creating a well defined thermocline.

At the Symposium on the Living Resources of the Continental Shelf from the Strait of Gibraltar to Cape Vert, organized by the International Council for the Exploration of the Sea in 1968 in Tenerife, Allain (1970a) presented a synthesis of studies on the hydrology of the northwest African coastal area. At that time, there was little data concerning the region to the south of Cape Juby. Nevertheless, the cruises of the "Meteor" in 1925 and 1927 (Wüst 1935; Bohnecke 1936; Defant 1936) and of the "Discovery II" (Worthington 1958) had already shown the existence of upwelling from mid-depths.

Several papers presented in the symposium gave evidence of various upwellings along the Northwest African coast between Cape Juby and Cape Vert. Jones and Folkard (1970) analysed the data from the cruises of the R.V. "Clione" (Summer, 1965), of H.M.S. "Hecate" (Spring, 1966) and of H.M.S. "Hydra" (Fall, 1967). They showed the existence of large areas of the Northwest African continental shelf where the surface waters are enriched in nutrients by a process of upwelling. Furthermore, they showed that the upwelling to the north of Cape Blanc (21°N) is not confined to the summer, and can also develop in other seasons. A good correlation was found between the wind system and the state of upwelling. Fedoseev (1970) found that it is in winter and in spring that the geostrophic circulation at the surface is the strongest, corresponding to a strengthening of the Trade Winds at this time between Cape Juby and Cape Blanc. Mascareno and Molina (1970) found an upwelling below Cape Juby to be more important in September 1966 than in March 1967. Wozniak (1970) studied the upwelling at Cape Blanc in June and July, 1963. In June, the upwelled waters originated from the Canary Current. In the latter month, stronger upwelling gave rise to warmer, more nutrient-rich water of tropical origin. These observations were confirmed for the months of June and July, 1967 by Wiktor and Chlapowski (1970) and for December 1962 by Allain (1970b). Mascareno (1970) showed the existence of an upwelling at Cape Leven (24°35'N) during the month of June 1968, when the water drawn from the Canary Current was progressively overlapped by a layer which was warmer and of greater salinity.

Following the symposium, which demonstrated the lack of in-depth studies concerning the phenomenon of upwelling and its effect on the biological productivity of the Northwest African coastal waters, an international research program was set up by the C.O.I. in 1969. The CINECA (Cooperative Investigations of the Northern Part of the Eastern Central Atlantic) program, carried out by the I.C.E.S., set up important means and a considerable research framework. The results were analyzed at several conferences: at Barcelona (March 1970), Marseille (May 1973), Kiel (August 1975); and were discussed at a symposium organized by the I.C.E.S. at Las Palmas in April 1978 (The Canary Current: Studies of an Upwelling System).

A number of important publications enables the identification of the general features of the upwelling along the Northwest African coast.

The overall distribution of the surface isotherms shows that the phenomenon takes place mainly between 12°N and 33°N (Schemainda et al., 1975; Wooster et al., 1976; Smed 1982). This large area is subdivided into three areas where the upwelling is influenced by the local meteorological and atmospheric conditions to which they are subjected.

To the north of 25°N, upwelling occurs mainly in summer. To the south of 20°N, it takes place in winter and spring. Between 20°N and 25°N, upwelling exists year round, with greater activity in the spring when the region of upwelling shifts to the north, and in fall, when it shifts towards the south (Speth and Detlefsen, 1982).

These three areas differ not only in their seasonal character, but also in the nature of the water which is upwelled. The two principal types of water involved in upwelling are the North Atlantic Central Water (NACW), which makes up the major part of the Canary Current, and the South Atlantic Central Water (SACW), which comes from the south. Fraga

(1973, 1974), Fraga and Manriquez (1974), Tomczak (1978, 1982), Manriquez and Fraga (1982), Fiuza and Halpern (1982), and Barton (1982) all agree in that the mixing front of these two types of water is in the region of Cape Blanc (21°N). The existence of a subsurface counter current taking SACW from north of Cape Blanc to about 25°N confirms the complex origin of the upwelled waters between 21°N and 25°N (Hughes and Barton, 1974; Mittelstaedt 1982). The upwelled water is made up of a mixture of NACW and SACW, modified at the surface by the original surface water (Tomczak 1977, 1978, 1982).

The SACW are richer in nutrient salts than NACW. This results in a gradient from south to north.

Minas et al (1982) presented a synthesis of studies on nutrient salts and primary production in this region at the Las Palmas symposium in 1978. We will refer to this work for a brief summary of the situation.

The north-south concentration gradient of mineral salts is not expressed by a similar gradient of primary production. Higher production rates take place to the south of Cape Blanc in the winter only. From Cape Blanc to Cape Barbas, the enrichment of upwelled NACW by the nutrient-rich SACW brought by the counter current, and the persistence of a year-round upwelling results in the highest annual rates of production in the region. Between Cape Barbas and Caoe Bojador, the extension and relative shallowness of the continental shelf, as well as its configuration, modify the upwelling by the persistence of a "cushion" of cold water, a well-developed thermocline, and thermal boundary. In summer, the upwelling at Cape Bojador, the upwelled water consists primarily of NACW. Despite being less rich in nutrients, primary production appears to be as important as in the south, due to highly efficient nutrient recycling.

We will examine the region between Safi and El Ayoun in greater detail because it is here that the principal sardine population, exploited by Moroccan boats, is found.

Except for the work of Furnestin (1959), the only knowledge on the upwelling and productivity of this region comes from the cruises of "J. Charcot" (CINECA I to V), analyzed by Grall et al. (1974), LeFloch (1974), Groupe MEDIPROD.(1974), Minas et al. (1974), LeCorre and Treguer (1976), Thiriot (1976), Huber et al. (1977), Treguer and LeCorre (1979), and Grall et al. (1982).

The region is divided into two distinct zones: the northern zone between Cape Sim and Cape Ghir, and the southern zone between Ifni and Cape Juby. The two zones are sites of upwelling where the source is from 150 m depth in winter, and 250 m in summer (LeFloch 1974; Grall et al., 1974). They are separated by warmer water in the Bay of Agadir, which is considered by Treguer and LeCorre (1979) to be older, rewarmed upwelled water.

In the northern part, the upwelling source is situated between Cape Sim and Cape Tafelney. The bottom topography allows a southwest extension from this source of a tongue of cold water, rich in nutrients. Between this tongue and the coast, a counter current transports warmer water from the Bay of Agadir to the north of Cape Ghir. This upwelling source is affected considerably by the local wind system. The local winds are stronger at the end of the day (30 knots), and weaker at the end of the night (10 knots) (Grall et al., 1982). This strengthening of the Trade Winds at the end of the day is due to the formation, in summer afternoons, of a small thermal depression in the Agadir plain (Richbé, pers. comm.). The effect of this pulsing phemomenon is important at the surface (cooling and increase in nutrient level). It is of little importance below 50 m where the upwelling is stable (LeSaos and Talarmin, 1976). Grall et al. (1982) have shown that there is a time lag of about three hours between the strengthening of the wind and its effects on the surface, and a time lag of about six hours between the weakening of the wind and the complete stratification of chlorophyll a. The highest rates of production (more than 3 g C/m$^2$/d) take place as the weakening of the wind reduces mixing and when there is advection of warm coastal water. Strong winds (35 m/s) cause powerful upwelling at the surface but hinder primary production by creating complete vertical homogeneity through vigorous mixing. Turbidity associated with strong mixing may also limit photosynthesis. The rate of production increases as the force of the wind diminishes.

In the southern area, between Ifni and Cape Juby, the continental shelf is wider and has a gentler slope. The winds are more regular and not as strong, being intermediate between the maxima and the minima of the northern area (20 knots). The cold waters of the upwelling appear at the surface only from time to time. A cushion of cold water over the continental shelf has physical and chemical characteristics similar to that of water found at 200-300 m depth, but has greater nutrient concentrations. This cushion is the site of important nutrient recycling, as shown by LeCorre and Treguer (1976). Grall et al. (1974) identified three levels of production corresponding to this water column formation. The upper surface level is warm and is poor in chlorophyll and nutrients. The intermediate level has strong temperature and nutrient concentration gradients. High concentrations of chlorophyll are found in bands of approximately twelve meters thickness. The lower level, site of nutrient regeneration, is rich in nutrients, but poor in oxygen and chlorophyll pigments.

Nutrient regeneration is an important factor in the upwelling of this region. The recycling of nutrient salts explains the high levels of productivity even though the nutrient concentrations in the upwelled water (NACW) are inferior to those of the regions to the south (SACW or a mixture of both). A table comparing nutrient concentrations and productivity of coastal waters from different areas, (Minas et al., 1982 modified from LeCorre and Treguer, 1976), shows that rates of production between Cape Sim and Cape Ghir in summer are comparable to those found off Cape Blanc.

Codispoti et al. (1982) have compared the characteristics of the upwellings of Lower California (27°N), of Peru (15°S), and of Northwest Africa (21°30'N). They show important differences in the flow of mineral salts, their assimilation and their regeneration. The upwelled waters of the Atlantic are poorer in nutrients and richer in oxygen than those of the Pacific. The relations between local winds and upwelling are more evident for the Northwest African coast than for Peru, where inter-annual variations are more pronounced. Rates of nitrate assimilation are higher in the Peruvian upwelling, but denitrification and occasionally, the production of hydrogen sulfide, may take place. The more powerful winds of the Northwest African coast give rise to strong mixing and important turbidity which may limit photosynthetic activity. The nutrient regeneration cycle differs for Peru, where the continental shelf is narrower and is swept by a current flowing offshore. The winds are weaker, allowing better stratification of coastal waters.

There are few studies on the relations between the productivity of the upwelling area and its stocks of fish. The extension towards the south of the region inhabited by the sardines, was explained by a strengthening of the upwelling in this region since 1970 by Holzlohner (1975) and by Sedykh (1978). Nehring and Holzlohner (1982) have shown that between Cape Bojador and Cape Barbas, there is a relationship between the average concentration of chlorophyll a, the total volume of sardine schools, and the daily catches of a trawler.

## MIGRATION OF THE SARDINES AND INDICES OF ABUNDANCE FOR THE REGION OF THE MOROCCAN FISHERY

### Migrations

The three sardine populations found on the Northwest African coast carry out seasonal movements along the coast. Furnestin (1959) and Bravo de Laguna et al. (1976) proposed a diagram of migration in relation to hydrological features. Belvèze and Bravo de Laguna (1980) took the data of earlier authors, and, using the observations of Krzeptowski (1975) and of Barkova (1976) as well as distribution charts obtained from acoustic surveys, suggested an overall hypothesis for these migrations. Since no tagging has been carried out with any success, this hypothesis was based partly on the activity of the fishing fleets and on the results of acoustic surveys. The three populations carry out synchronous movements toward the south in winter and toward the north in summer (see Figure 2).

The small northern population extends from the Strait of Gibraltar to El Jadida in winter. In summer, it withdraws to the area between Larache and Tangier, where there is summer upwelling. The sardine fishery at Casablanca takes place mainly from the end of fall to spring. Conversely, the greatest activity in Tangier and Larache is during summer and fall.

In winter, the central population leaves fishing zone A (between Safi and Ifni) and concentrates in fishing zone B (between Ifni and El Ayoun), where the region of maximum reproduction is found. In spring, the population migrates partially to the north, and in summer, occupies all the area between Safi and El Ayoun (zone A + B). It is thus a spreading out of the population in summer and a aggregation in winter rather than an overall migration of the stock. A certain portion of the stock may remain during winter between Safi and Agadir (zone A) and gives rise to a winter or spring fishery for boats based at these ports. The majority of the Moroccan catch takes place in summer and in fall, when the sardines coming from the south enter fishing zone A. To the south, in fishing zone B, acoustic surveys have shown that the sardine is abundantly present all year round between Ifni and El Ayoun. The fishing season of the boats based at the Canary Islands extends year round, but the best catches take place in the fall, when the sardines concentrate in zone B for spawning (Delgado and Fernandez, 1982).

The southern population carries out movements along the coast similar to those of the populations found north of it. The spacial-temporal distribution of Polish factory-trawlers, as presented by Wisokinski (1980), shows that in winter, the boats are concentrated between 22°N and 25°N. In spring, they shift northward, and in summer-fall, they are found between 24°N and 25°N. It is difficult to know whether the sardines which are found during the summer and fall in the region of El Ayoun (between 26°30'N and 28°N) belong to the northern part of the southern population or to the southern part of the central population. The hypothesis that a certain amount of mixing occurs between the two populations, proposed by Bravo de Laguna et al. (1976) and Fernandez et al. (1978), cannot be ignored. Acoustic surveys show a division in the distribution of sardines at the level of Cape Bojador in November (Marchal and Boely, 1977; Lamboeuf, pers. comm.) and February (Bencherifi, pers. comm.). There is also a division at the level of El Ayoun in July (Lamboeuf et al., 1981). However, there was no division between 30°N and 24°N in October (Lamboeuf, pers. comm.). The southern limit of this population has changed with time, as shown by Holzlohner (1975) and Domanevsky and Barkova (1981), without affecting the general form of the seasonal movements.

Thus, the three populations move in a more or less synchronous manner toward the north in summer and toward the south in winter. These movements have little effect on fisheries B and C, where the boats can follow the areas of greatest abundance. However, fishery A, where boats operate close to port and have a limited sphere of action, is strongly affected by the seasonal movements of the central sardine population.

## Indices of Abundance for the Moroccan Fishing Zone (Zone A)

Fishing effort of Moroccan sardine boats based at Safi, Essaouira and Agadir, and operating in fishing zone A, was calculated by multiplying the gross tonnage of each boat by the number of daily trips carried out in a month (Belvèze, 1974, 1981).

Annual fishing effort was obtained by calculating the sum of the monthly efforts, weighted by an index of average monthly relative abundance, in order to take into account the availability of the sardines and the length of the fishing season during the year. The effective fishing intensities were calculated as a function of the surfaces of the fishing area for each port and weighted by the fish densities according to the method of Beverton and Holt.

Data are available for the period from 1968 to 1981. The monthly CPUE averages during this period change seasonally, with a minimum in winter and a maximum in summer (Figure 6). The sardine is on the average more abundant in the fishing area of Agadir than in the area of Safi/Essaouira. These variations in CPUE through the year reflect the sardine movements considered earlier. From December to March, the small part of the stock which remains in Zone A during winter, is fished. Starting from April in Agadir and May

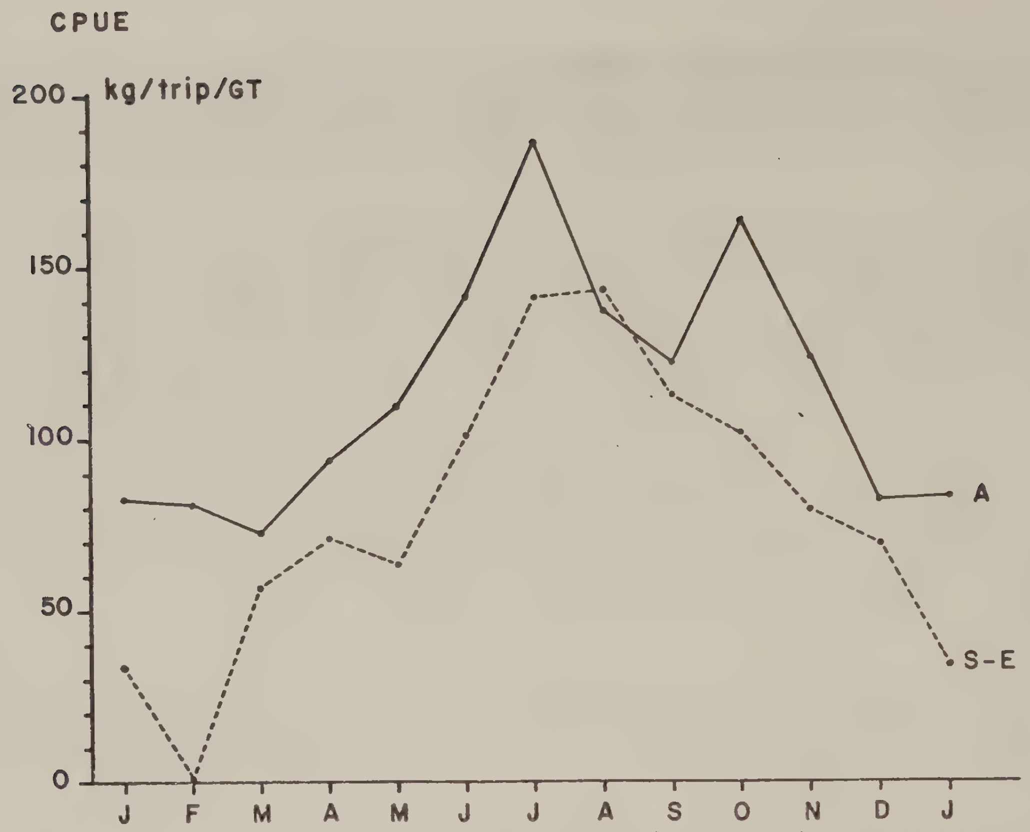


Figure Nº 6: Monthly means of catches per unit effort in the fishing zones of Agadir and of Safi-Essaouira in kg per trip per ton of gross tonnage.

Table 1: Annual catch, effective fishing intensity and index of abundance for zone A for the period from 1968 to 1981.

| Year | Catch (tons) | Effective fishing intensity | Index of abundance |
|---|---|---|---|
| 1968 | 155 397 | 851.1 | 182.6 |
| 1969 | 157 168 | 821.8 | 191.2 |
| 1970 | 150 233 | 1020.7 | 147.2 |
| 1971 | 172 676 | 1256.3 | 137.4 |
| 1972 | 159 211 | 1284.6 | 123.9 |
| 1973 | 326 261 | 1400.1 | 233.0 |
| 1974 | 204 231 | 1278.1 | 159.8 |
| 1975 | 146 614 | 1246.9 | 117.6 |
| 1976 | 176 162 | 1410.5 | 124.9 |
| 1977 | 101 877 | 1291.0 | 78.9 |
| 1978 | 91 141 | 1270.3 | 71.7 |
| 1979 | 163 442 | 1543.4 | 105.9 |
| 1980 | 181 198 | 1660.8 | 109.1 |
| 1981 | 200 395 | 1578.1 | 127.0 |

in Safi/Essaouira, the CPUE increases due to the progressive arrival of sardines from the south. The maximum is reached in July at Agadir and in August in Safi/Essaouira. A second peak takes place in Agadir in October and is probably linked to the return movement towards the south from the region of Safi/Essaouira. Agadir is the first port in the path of migration and therefore, is closest to zone B, where the sardines concentrate in winter. Thus, Agadir has an advantage with respect to the other more northerly ports.

Overall, the annual variations in abundance may be related to the seasonal character of the upwelling, as will be shown further on (Figure 10). The maximum abundance coincides with the period during the summer of greatest upwelling. One is thus tempted to link abundance and upwelling, and to explain the movements of the sardines by attraction to areas of high productivity. Since upwelling occurs in zone B as well, it is only part of the stock which migrates towards zone A in summer. Therefore, the availability of sardines in zone A depends not only on the size of the stock, but also on the rate of migration caused by the summer upwelling. Variations in the amount of upwelling may thus cause variations in the availability of sardines in zone A.

The catches, the effective fishing intensities and the annual indices of abundance for zone A from 1968 to 1981 can be seen in Table 1. Effective fishing intensity rose from 1968 to 1981, but was relatively stable from 1971 to 1978. Indices of abundance decreased from 1968 to 1978, despite a big increase in 1973. Since 1979, the trend has reversed, although fishing intensity is increasing. The rapid increase in 1973 of the index of abundance and its subsequent decrease while fishing intensity remained relatively stable, indicates that some factor other than fishing affected the abundance of sardines in this zone. One is tempted to explain the decrease in abundance in zone A by the development of a fishery in zone B (cf. Figure 2). It is likely that the growth in catches in zone B may be part of the cause for the sharp drop in abundance in zone A, that has taken place in the past ten years or so. This does not explain the big increase in 1973, nor the increase in the CPUE since 1978 while the fishing intensity increases in zone A. There are probably some fluctuations in abundance and in availability between zones A and B due to natural reasons (Figure 7).

To sum up, fisheries A and B exploit the same stock. Absolute variations in abundance affect the two fisheries, but fishery A (Moroccan) is additionally subjected to fluctuations in availability caused by seasonal migration of one part of the stock outside the sphere of activity of the boats.

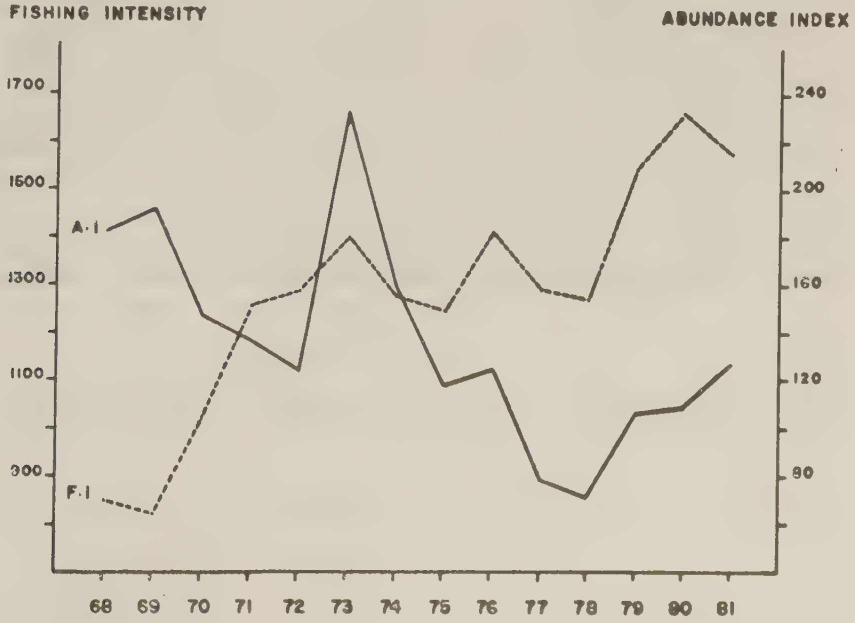


Fig. 7. Fishing intensity and indices of abundance for the whole of fishery A (Safi-Essaouira-Agadir) from 1968 to 1981.

## RAINFALL AND CATCHES OF SMALL PELAGIC FISH IN MOROCCO SINCE 1936

Moroccan catches of sardines in zone A, landed in the ports of Safi, Essaouira and Agadir increased progressively from 1945 to 1965 with the development of the sardine fleet. Since 1965, catches have stabilized at an average of 160,000 tons a year, with some large variations. We have seen that due to the geographical position and the lack of cruising range of the Moroccan sardine fleet, the fishery is heavily dependent on the availability of the sardines within zone A. Belvèze (1974) has shown the coincidence of years of exceptionally high catches and years of big droughts at the coast from 1950-1973 and put forward a hypothesis of a seven- to eight-year cycle.

### Data

Rainfall. Rainfall is a parameter that has been recorded by coastal meteorological stations since 1936 at Agadir, and since 1955 at Safi and Essaouira. It is expressed in millimeters of water that has fallen for each year. For the period from 1955-1981, a comparison of rainfall at Safi-Essaouira and Agadir gave a positive correlation (r=0.71). A functional regression between the two series of data allows us to estimate rainfall at Safi-Essaouira for the period from 1936-1954. Thus, the total rainfall for this zone since 1936 can be calculated. The data is presented in Appendix 1.

Coastal rainfall of zone A (Figure 8) shows a succession of minima (exceptionally dry years), which occur with a certain regularity 1937-1944 (seven years); 1944-1950 (six years); 1950-1958 (eight years); 1958-1966 (eight years); 1966-1973 (seven years); 1973-1981 (eight years). Except for 1966, these years are followed by one or two dry years before the rainfall increases again.

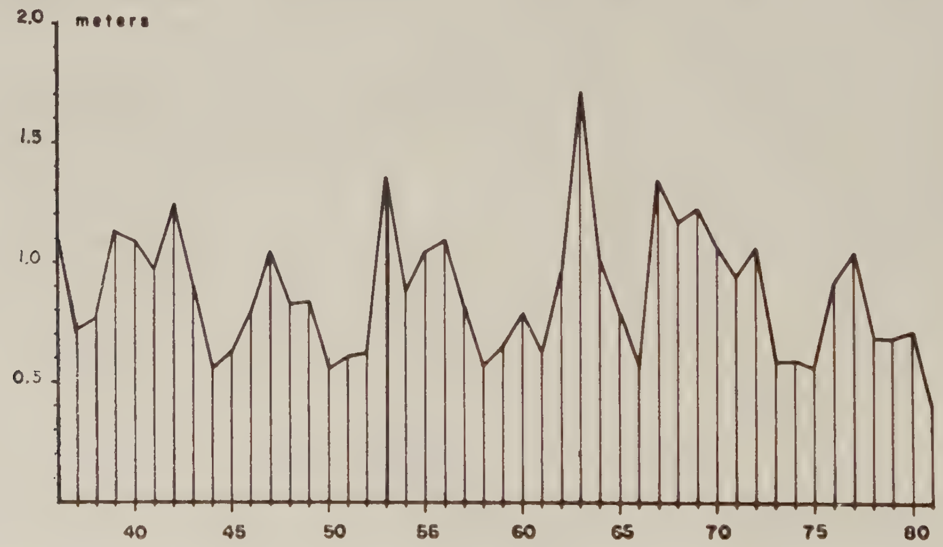


Fig. 8. Total coastal rainfall recorded at Safi-Essaouira-Agadir in m from 1936 to 1981.

## Catches

Four main species are present in the catches of seiners. In order of importance, they are: the sardine (*Sardina pilchardus*) which is by far the dominant species; the mackerel (*Scomber colias*), with small amounts of the European species (*Scomber scombrus*) appearing when coastal waters are warm. The horse mackerel (*Trachurus trachurus* and *Trachurus picturatus*) of which the first, essentially neritic, makes up most of the catch, while the latter, more oceanic, appears only rarely in the landings. The anchovy (*Engraulis enchrasicholus*) is of little importance in the catches except in certain years such as 1970 and 1977.

In 1977 and 1978, sardine catches and catches per unit of effort were very low (Figures 3 and 7). At the same time, catches of mackerel and horse mackerel were exceptionally high, compensating for the lack of sardines and maintaining total landings of small pelagics at a level equivalent to other years. Annual catches for each species from 1960 to 1981 are given in Appendix II. The proportion of sardines in the total catch was greater than 90% until 1975. As there has not been a change either in fishing methods or in the area of exploitation of Moroccan seiners, the proportional decline in sardines is probably related to a change in relative availability of the different species.

Catches of small pelagics in zone A reflect those of the sardine, which is the dominant species, except for 1977 and 1978. The evolution of the catches is characterized by a succession of more or less stable stretches between maxima. These maxima were less pronounced before 1966, probably because individual capacity of the boats was still small and saturation would have limited large catches at times of great abundance. Since seining did not develop till after World War II, the catches of small pelagics from 1947 to 1981 in comparison with annual rainfall can be seen in Figure 9.

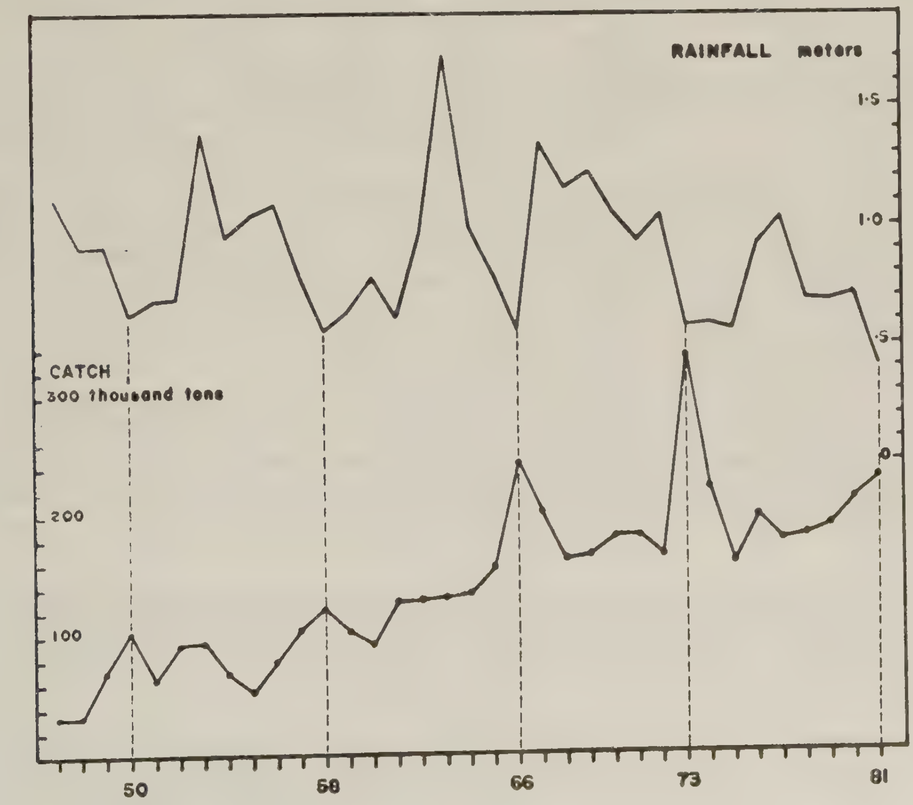


Fig. 9. Coastal rainfall (m) and catches of small coastal pelagics (thousands of tons) in zone A from 1947 to 1981.

## Results

A graphical comparison of catches and rainfall from 1947 to 1981 shows the correspondence of exceptionally dry years with large catches. The hypothesis of a seven- to eight-year cycle put forth in 1974, seems to be confirmed by a dry year with increased catches in 1981. When several dry years follow, the important increase in catch takes place in the first year and not the following (cf. 1975). The years of very heavy rainfall, such as 1953, 1963 and 1967, do not result in any perceptible decrease in catch. It appears that rainfall has an effect on catches only in the case of extreme drought.

In order to measure the relative difference with respect to an average, the general average of the catches from 1947 to 1981 could not be used since catches have increased progressively with the development of the fishing fleet. The differences were calculated as percentages of annual values in comparison with a running average of nine corresponding years.

The results are given in Appendix III. A graphical representation shows the dispersion of the points with regard to the slope of the functional regression. The coefficient of correlation for the two series of annual values, Δ C% and Δ %R is -0.47. The correlation between rainfall and catch exists, but it is not a straight one (Figure 10).

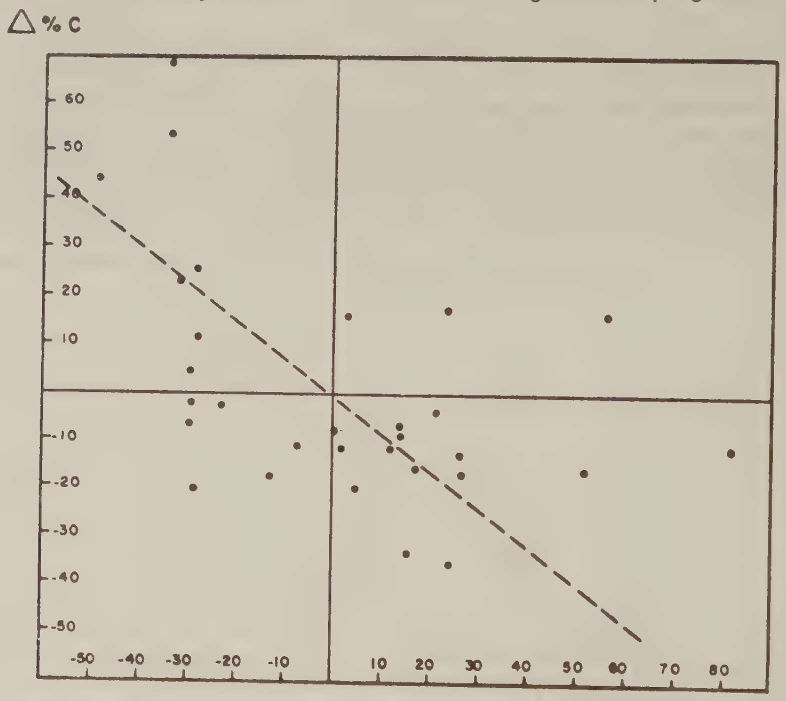


Fig. 10. Linear regression between deviations from mean rainfall Δ%R (as a percentage) and deviations of catches from a running 9-year average, Δ%C (as a percentage).

## Discussion

Bakun and Parrish (1980) have emphasized the difficulty of testing a hypothesis when the same data were used to formulate the hypothesis. We will be content with the discussion of the empirical relation between rainfall and catches of small pelagics in zone A, without taking it as proof of the theory.

Rainfall may have an enriching action by the supply of mineral salts through river runoff. This supply is of greater importance when surface vegetation is poor and erosion is active, as is the case in Morocco. In this case, a period of abundant rainfall results in increases in primary production and then, stocks of fish. After a certain time lag, it translates into increases in catch, as is the case in the Moroccan fishery. Belvèze (1974) suggested that coastal rainfall does not act by itself, but is the reflection of a certain type of climatic condition in the area. The dry years are therefore, years when the Trade Winds remain for a long time, limiting rainfall to a brief winter period. There would then be an agreement between the dry years and the strengthening of upwelling in the zone. This strengthening would be the cause of greater availability of fish, primarily sardine, which would have earlier and more important migration from the south to zone A.

# ANALYSIS OF THE CHANGES IN STRENGTH AND DIRECTION OF WINDS AT THE CENTER OF THE MOROCCAN FISHERY (ZONE A) AND THEIR INFLUENCE ON THE AVAILABILITY OF THE SARDINE

## Data

Choice of station. Wind recordings are made daily at Safi, Essaouira and Agadir. The station at Essaouira was used for the wind study for several reasons. This station is situated at the center of zone A, approximately halfway between Safi and Agadir, in the region where the major upwelling takes place. The anemometer is on a 12-m high tower bordering the sea. At Safi and Agadir, they are placed more inland (airport). Essaouira is on a flat coastline, slightly convex towards offshore, while Safi and Agadir are located along bays protected by the cliffs of Cape Cantin and the Atlas mountain chain at Cape Ghir. Furthermore, Richebē (in press), has shown the existence of a zonal pressure gradient between Safi and Agadir, particularly important in summer when a thermal depression forms at the end of the day on the Agadir plain. This gradient gives rise to a strengthening of the Trade Winds at Essaouira in the afternoon, followed by a weakening at the end of the night.

The wind at Essaouira. Wind speed (in m/s) and direction (in degrees) have been recorded at least three times a day: at 06 h, 12 h and 18 h, since 1945. Data were compiled by Richebē (in press) who calculated the average of the north-south and east-west projections and recalculated the average speed and direction on a daily, weekly, monthly and annual bases. The variances of the annual means were also determined. Values of annual means and their variances are shown in Appendix IV.

## Results

Monthly variations. The monthly averages of wind speed and its north and east components for the period from 1945-1980, are given in Table 2, and represented graphically in Figure 11.

We can see the year-round predominance of the north component, which at Essaouira, characterizes the Trade Wind. The latter generates upwelling since the coast is oriented roughly along the north-south direction. Wind speed follows a seasonal cycle with a minimum in winter and a maximum in summer, which conforms with the general hydroclimatical scheme for this area. The evolution of the monthly CPUE for the Safi/Essaouira zone (Figures 6 and 11) shows a parallelism with the average north component of the wind at Essaouira. The increase in wind speed translates, after a time lag, into an increase in CPUE. It is probable that the first relatively modest peak in CPUE in April following a strong increase in the north component of the wind, is due to the concentration in the fishing area of sardines which pass the winter in zone A. The big increase in CPUE in June and July reflects the arrival of sardines from the south. The maximum CPUE corresponds to the maximum speed of the north wind component in August. The decline in CPUE from September is less rapid than the decrease in wind speed.

The upwelling induced by the wind from the north is theoretically proportional to the square of the speed. It appears that there could be a cause-and-effect relation between monthly variations in upwelling and catches per unit effort in this zone. In this case, upwelling acts with hardly any delay on the relative abundance, as well as on the availability of sardines in the fishing zone. Since the area where the greatest amount of reproduction takes place is further south, between Ifni and Cape Juby, it is not very likely that fluctuations in upwelling in the region of Essaouira have a major effect on the total abundance of the population.

Long-term variations. Two aspects of the changes in the wind blowing at Essaouira from 1945 to 1980 must be examined: speed and direction. The average annual values of these two parameters given by Richebē (Appendix IV), are represented graphically in Figure 12.

Table 2: Mean monthly wind speed, and the North and East componente of the wind at Essaouira, in m/s, for the period from 1945 to 1980.

| Month | Mean monthly wind speed | North component | East component |
|---|---|---|---|
| January | 1.90 | 0.95 | 0.76 |
| February | 2.21 | 1.35 | 0.49 |
| March | 2.21 | 1.73 | 0.26 |
| April | 3.42 | 3.03 | 0.53 |
| May | 3.76 | 3.27 | 0.82 |
| June | 4.23 | 3.66 | 1.26 |
| July | 5.29 | 4.42 | 1.67 |
| August | 5.14 | 4.61 | 1.53 |
| September | 3.65 | 3.25 | 0.73 |
| October | 2.56 | 2.08 | 0.68 |
| November | 1.63 | 1.16 | 0.49 |
| December | 2.05 | 1.28 | 0.74 |

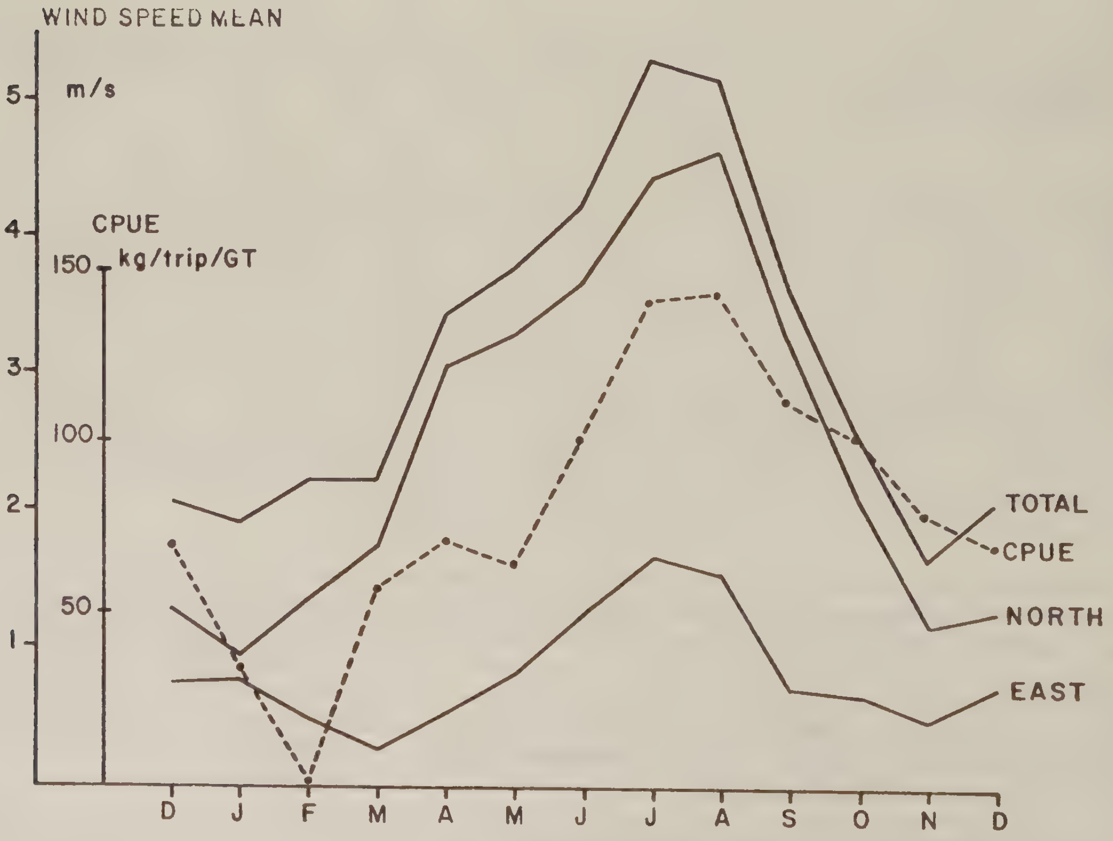


Figure Nº 11: Mean monthly wind speed and its north and east components at Essaouira (1945-1980) in m/s, and mean monthly CPUE of sardines at Safi-Essaouira (1968-1981)

Two observations can be made from Figure 12. First, the average wind speed at Essaouira has diminished progressively since 1945, while displaying inter-annual fluctuations of a certain amplitude. This decline has been particularly marked since 1975, the observed average speeds being inferior to the slope of the regression line for the period from 1945 to 1980. Faced with this result, there was some concern as to the viability of the anemometers. The long-term decrease could be due to fatigue. After an inquiry, it turned out that the anemometers could not be at fault. Their dates of verification or replacement did not correspond to significant changes in recorded wind speed.

Second, the average direction of the winds has also changed within this 35-year period. Between 1945 and 1960, the azimuth oscillated between 350° and 20° (average: 5°). Between 1961 and 1980, the azimuth varied between 350° and 60° (average: 26°). Since 1960, there has been a small shift toward the east in the average direction of the winds.

These long-term changes in average wind speed and direction at Essaouira have probably had repercussions on the productivity of the Safi/Essaouira region.

Wind speed and sardine catch. Catches of sardines in the Safi/Essaouira fishery increased till the end of the 50's because of the growth of the fleet and technological improvements in the form of synthetic fiber nets and sounders. Starting from the beginning of the 60's, catches levelled off at about 70,000 tons as the size of the fleet increased only slowly. Catch per unit effort is a better indicator of local sardine abundance but accurate data are not available for the Safi/Essaouira area before 1970.

Average wind speed represents the energy which drives the pumping of nutrient salts from depth, since the average orientation of the winds remains more or less parallel to the coast (about 20°). We know that the action of the wind is proportional to the square of its speed. We also know from the work of Grall *et al.* (1982) in this region that mixing limits primary production and that primary production is more important when the winds weaken after a period of strong activity in which nutrient salts are brought up to the euphotic zone. The force of the wind thus plays an important role in enriching the environment and its variability allows better utilization of the nutrients in photosynthesis. In order to take into account these two factors, annual catch and CPUE were compared successively with the square of the average wind speed, its variance and both at the same time. The data used is given in Table 3.

Correlation coefficients for the different regressions are the following:

Simple correlations (Figures 13 and 14):

| | catch | CPUE |
|---|---|---|
| (mean wind speed)$^2$ | r = +0.734 | r = +0.736 |
| variance of the mean | r = +0.405 | r = +0.837 |

Multiple correlations:

| | catch | CPUE |
|---|---|---|
| (mean wind speed)$^2$ = $x_1$<br>variance of the mean = $x_2$ | r = +0.771 | r = +0.916 |

$$\text{Catch} = 9.92 + 2.39\,x_1 + 9.02\,x_2$$

$$\text{CPUE} = 8.01 + 1.95\,x_1 + 27.93\,x_2$$

With: catch in thousands of tons
CPUE in kg per trip and per ton of gross tonnage
mean wind speed in $(m/s)^2$
variance of the mean in m/s

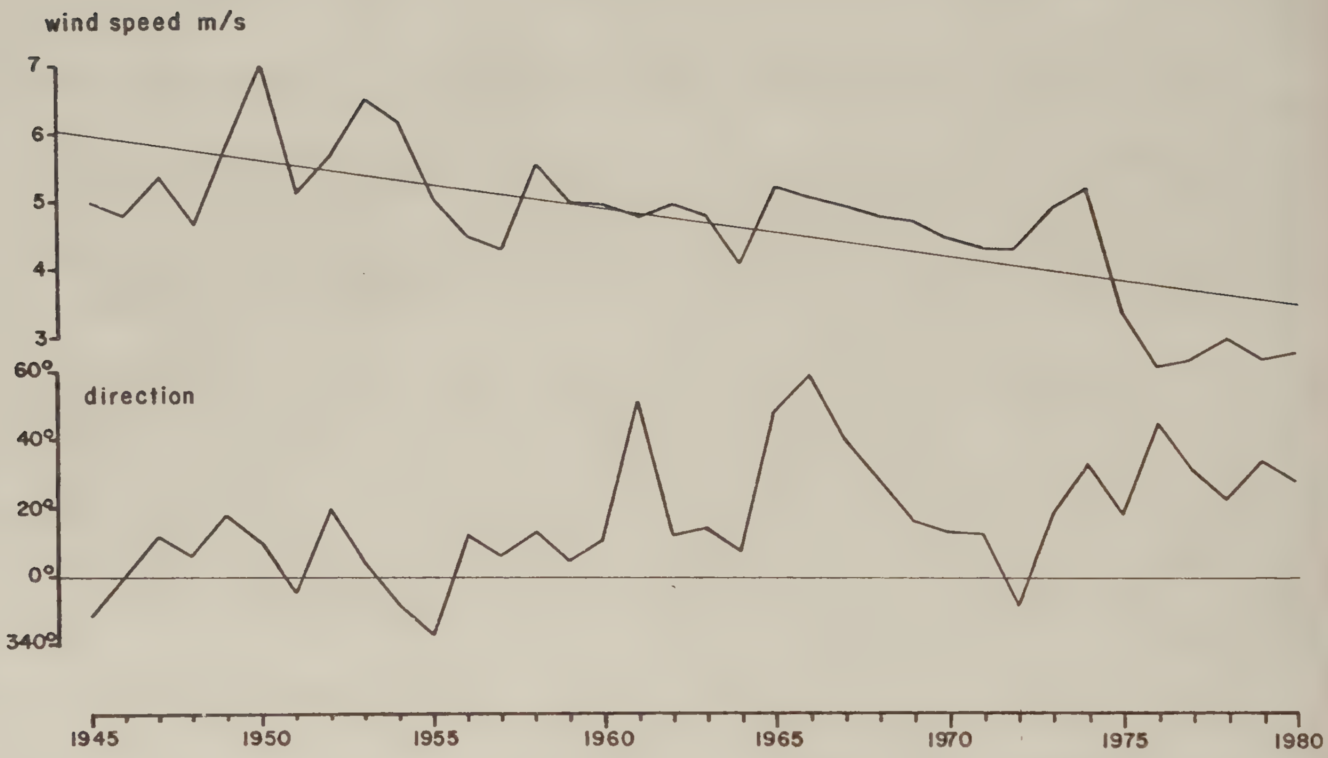


Figure Nº 12: Mean annual speeds and directions of the wind at Essaouira from 1945-1980

Table 3: Catch and CPUE of sardines in the Safi/Essaouira fishery, square of mean wind speed and variance of the mean at Essaouira.

| Year | Square of mean speed (m/s)$^2$ | Variance of mean speed (m/s) | Sardine catch in thousands of tons | CPUE Kg |
|---|---|---|---|---|
| 1963 | 22.8 | 1.68 | 76 | - |
| 1964 | 16.7 | 1.40 | 71 | - |
| 1965 | 27.1 | 2.09 | 84 | - |
| 1966 | 25.3 | 3.32 | 123 | - |
| 1967 | 24.2 | 1.63 | 124 | - |
| 1968 | 22.8 | 1.57 | 83 | - |
| 1969 | 22.1 | 2.10 | 79 | - |
| 1970 | 19.7 | 2.28 | 77 | 128.2 |
| 1971 | 18.4 | 2.31 | 53 | 95.5 |
| 1972 | 18.5 | 1.65 | 55 | 90.5 |
| 1973 | 23.7 | 4.33 | 109 | 185.9 |
| 1974 | 26.8 | 2.38 | 64 | 115.9 |
| 1975 | 11.0 | 2.25 | 56 | 92.1 |
| 1976 | 6.5 | 1.26 | 36 | 78.0 |
| 1977 | 7.0 | 2.53 | 45 | 85.6 |
| 1978 | 8.6 | 1.96 | 31 | 59.6 |
| 1979 | 6.9 | 1.99 | 65 | 87.4 |
| 1980 | 7.7 | 2.25 | 53 | 74.8 |

These coefficients are all significant. The wind speed and its variation at Essaouira explain close to 84% of the variance in local sardine abundance, i.e. its availability within the fishing zone of the sardine boats from these ports. These two meteorological factors act together. They are not linked together by a significant correlation (r = 0.24). The agreement between the different factors and the local abundance for the same year shows that it is an availability of adult sardines in the fishing zone, and not a real increase in the stock by more important recruitment, the effect of which would only be felt in the following years.

Richebē (in press) carried out regressions between mean monthly wind speed (m/s) and monthly landings of sardines at Safi-Essaouira (tons) from 1965 to 1980 (192 mos.). He found a correlation coefficient of r = +0.43 in comparing landings and winds for the same months. When he compared landings with winds of the preceding month, a higher correlation coefficient was obtained: r = +0.53, which is quite significant. These coefficients are smaller than those calculated on an annual basis, probably because the fleet lays up for the winter for repairs and because catches are too small. These months of inactivity were nevertheless taken into account in the calculations of the correlations. This correlation measures the amount of connection between the two data series which vary in a cyclical manner through the year, and also on a long-term basis.

The authors have also calculated a monthly index of Ekman transport perpendicular to the coast from speeds and directions of winds observed at Essaouira. This monthly index was compared with landings of sardines a month later at Safi-Essaouira and a correlation coefficient of r = +0.46 was obtained. This index explains only 21% of the variance of the landings. It is probable that Ekman transport is not a very good index of primary production in the region of Essaouira because it does not bring in short-term factors of wind variability.

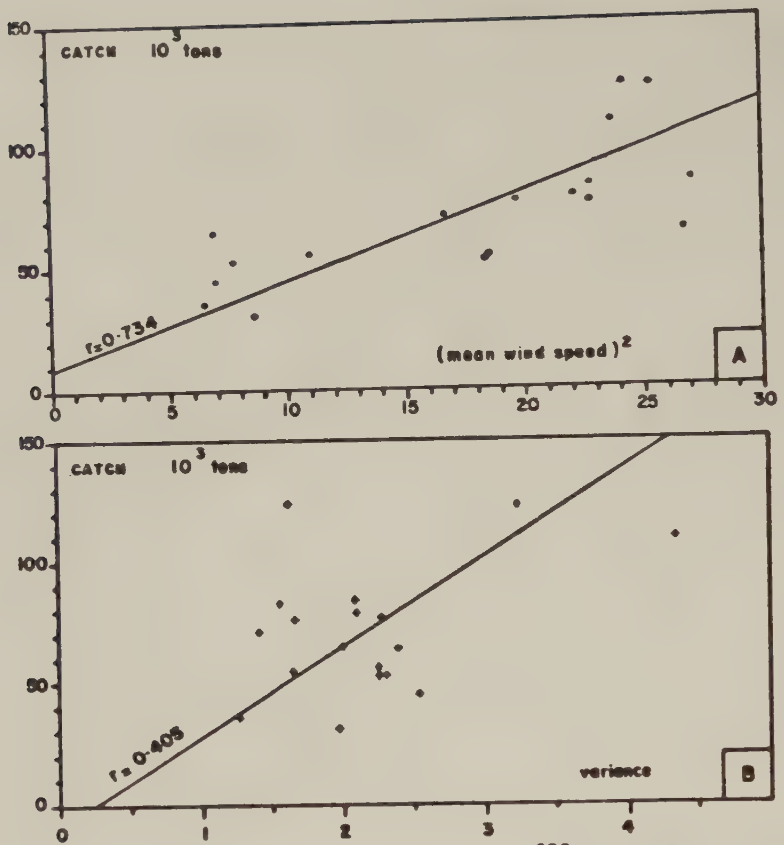


Figure Nº 13: Regression between annual catches of sardines at Safi-Essaouira in thousands of tons from 1963 to 1980 and:

A. The square of mean wind speed $(m/s)^2$ at Essaouira.

B. Variance of mean wind speed (m/s) at Essaouira.

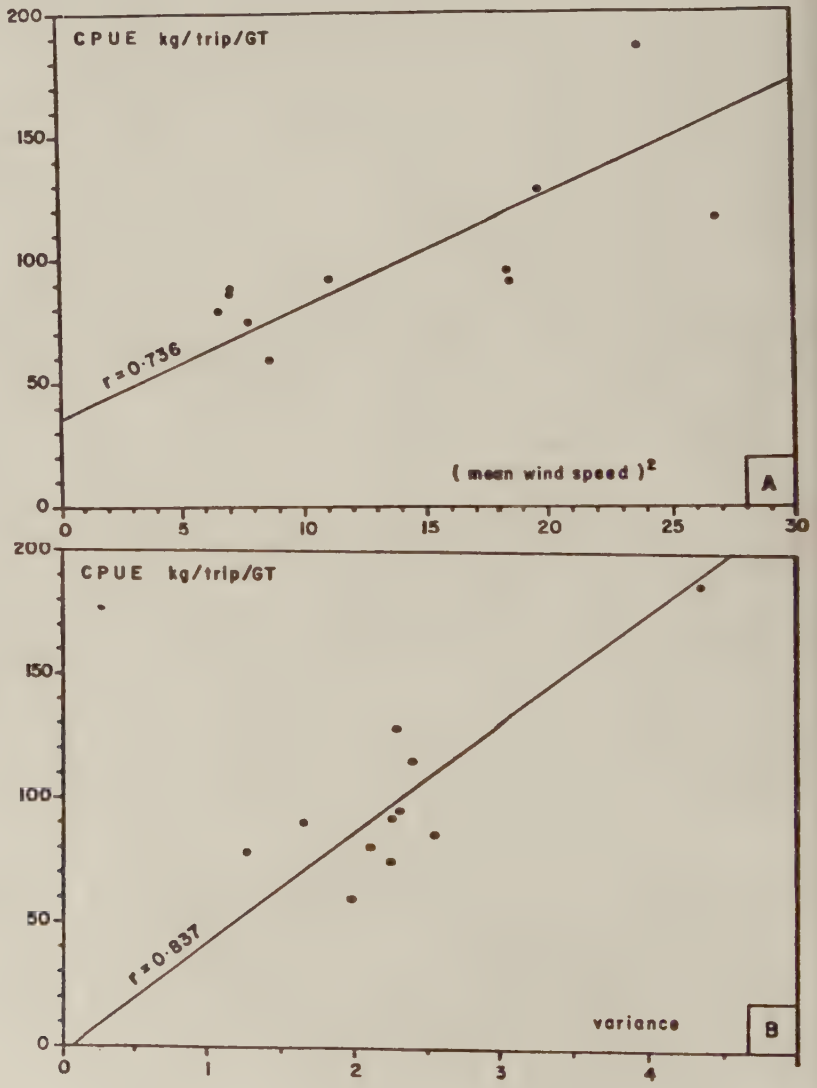


Figure Nº 14: Regression between annual CPUE at Essaouira in kg/trip/ton of gross tonnage from 1970 to 1980 and:

A. The square of mean wind speed $(m/s)^2$ at Essaouira.

B. Variance of mean wind speed (m/s) at Essaouira.

Generally, when the sardines are absent in winter and are found several hundred kilometers to the south of Safi-Essaouira, the occurrence of north winds does not provoke an immediate reaction in terms of local abundance, and does not increase catch. Mean annual data aggregates wind and catch factors for the whole of the fishing season, and gives better correlations.

In conclusion, the decrease in availability of sardines in the fishing zone of Safi-Essaouira is caused largely by a weakening of the trade winds and attenuation of their short-term fluctuations. The remaining variance, that is not explained by the correlation, could be partly due to real variations in abundance of the stock, and partly because the fleet at Agadir takes increasingly important amounts of sardines along the migration path. The real or actual abundance of the stock is primarily controlled by enfironmental factors to the south of Agadir, where the major part of the population is found and where the winter and spring reproduction takes place; and secondarily, by the catch from zones A and B.

## ABUNDANCE OF SARDINE AND INDICES OF UPWELLING IN THE SOUTH OF THE MOROCCAN FISHERY (ZONES B AND C)

### Zone B

We have seen that in winter, the sardine stock is concentrated in zone B and extends partially into zone A in summer. Spawning takes place primarily in winter and in spring, and it is probable that environmental conditions in zone B have an effect on recruitment and thus, on stock abundance. It is also possible that sardines of zone C may enter the southern part of zone B in autumn.

Available data. With regard to abundance, the variations in availability in zone A considered earlier do not allow the use of CPUE to determine a real index of abundance of the stock. Unfortunately, a corresponding series of CPUE for zone B is not available. Data on total catches are available since the start of the fishery (1965), but were of low values since the fleet was then small and perhaps, statistics were insufficient. Regular sampling of catches did not start till 1973 in zone A, and not till 1976 in zone B. The distribution of age classes in the two fisheries are different and do not allow the extrapolation of age composition of catches of zone A to catches of zone B. The sardines fished in zone A are, on the average, younger. Cohort analysis of the whole stock is therefore, limited to six years only (1976-1981). Catch by age class data submitted to the Ad hoc Working Group on the Sardine of the CECAF by Belvèze (1981), Delgado *et al.* (1979, 1982), and Fernandez (pers. comm., 1981) were regrouped. Cohort analysis using $M = 0.6$ and $F_t = 0.5$ gave estimates of recruitment, abundance and biomass for the first of January, as shown in Table 4.

Table 4: Recruitment, abundance and biomass of the sardine stock (zones A and B) calculated by cohort analysis, with $M = 0.6$ and $F_t = 0.5$

| Year | Recruitment ($10^9$ sardines) | Abundance ($10^9$ sardines) | Biomass ($10^3$ tons) |
|---|---|---|---|
| 1976 | 9.6 | 31.7 | 1034 |
| 1977 | 11.4 | 25.4 | 676 |
| 1978 | 35.3 | 46.9 | 732 |
| 1979 | 13.3 | 36.6 | 702 |
| 1980 | 38.3 | 55.0 | 936 |
| 1981 | 31.5 | 57.5 | 954 |

The stock suffered a significant reduction in 1977. Following higher recruitment in 1978, 1980 and 1981, biomass rose in 1981 to a level almost equivalent to that in 1976, with abundance in numbers of fish being much greater. High recruitment in recent years has brought about a significant rejuvenation of the stock. An increase in exploitable biomass may be expected.

With regard to upwelling indices, the only available series is that provided by Bakun. He calculated a monthly upwelling index from 1946 to 1981 for 28°N, 13°W. This is near Cape Juby, which is in the southern part of zone B. This index was obtained by calculating the winds produced by atmospheric pressure fields and by corresponding Ekman transport. Details of the method of calculation and its limitations are given in Bakun (1973). From this monthly index, an index of mean annual upwelling from 1946 to 1981 was calculated (Figure 15). These annual values and their deviations from the overall mean for the period are given in Appendix V. From 1946 to 1959, they are below the mean, with the exception of 1954. Since 1970, values have all been above the mean. It appears, then, that the upwelling in this zone has an opposite tendency with respect to the northern zone upwelling. This conclusion must be considered with prudence because Bakun (pers. comm., 1973) has emphasized that these calculations may be bad indicators of long-term variations, since the system of atmospheric pressure data collection has changed with time. They may be more useful for short-term intra- and inter-annual comparisons.

Results and discussion. If we make the hypothesis that fluctuations in upwelling bring about parallel variations in population abundance by means of recruitment, effects on biomass would require a certain time lag. Catches may serve as an index of abundance if fishing effort remains more or less stable during a period of many years. As the sardine catch in zone B is composed mainly of fish of one, two and three years old, annual catches should be compared with the average upwelling index of the preceding three years. Data are shown in Table 5, and the graphical representation in Figure 16.

Table 5. Sardine catch in zone B (in thousands of tons), upwelling index and mean upwelling index for the preceding three years (in tons/s/100 m).

| Year | Catch | U.I. | Mean U.I (preceding 3 years) |
|---|---|---|---|
| 1970 | 50.5 | 187.3 | 161.1 |
| 1971 | 55.5 | 168.3 | 167.7 |
| 1972 | 46.9 | 183.7 | 157.9 |
| 1973 | 67.6 | 218.8 | 179.7 |
| 1974 | 86.2 | 213.1 | 190.2 |
| 1975 | 135.7 | 223.8 | 205.2 |
| 1976 | 121.2 | 179.4 | 218.6 |
| 1977 | 132.0 | 187.2 | 205.4 |
| 1978 | 125.7 | 185.9 | 196.8 |
| 1979 | 90.9 | 175.3 | 184.2 |
| 1980 | 85.0 | 226.4 | 182.8 |
| 1981 | 95.8 | 220.3 | 193.7 |

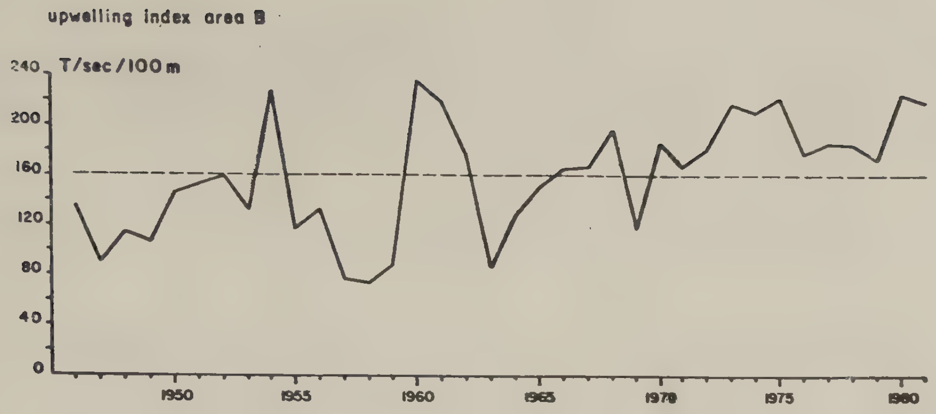


Figure Nº 15: Mean annual upwelling index from 1946 to 1981 for 28ºN by 13ºW in tons/s per 100 m width, calculated from the monthly data of Bakun.

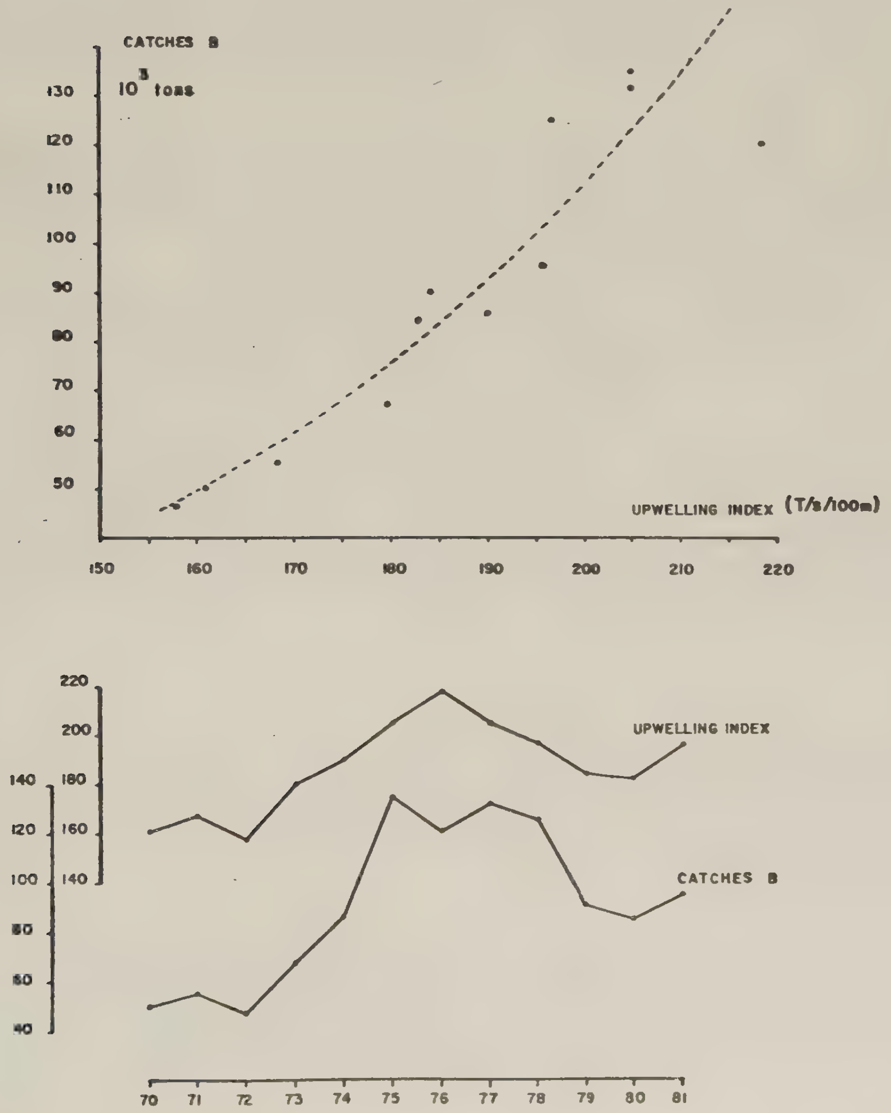


Figure Nº 16: Catches of sardines in zone B (thousands of tons) as a function of the average of the upwelling indices for the preceding three years (tons/s per 100 m width).

A functional linear regression using the twelve pairs of data gives a high correlation coefficient of $r = +0.930$. A regression using logarithmic values results in a slightly higher correlation coefficient of $r = +0.953$. These are both significant at the 99% level. The linear regression is expressed by:

$$C = 1.717\ \overline{\text{U.I.}} - 230,$$

and the curvilinear regression passing through the origin is given by:

$$C = 2.7 \times 10^{-7}\ \overline{\text{U.I.}}^{\,3.747}.$$

At first sight, we might consider tha hypothesis to be realistic and that catch is strongly linked (90% of the variance is explained) with the average upwelling of the preceding three years. It is fitting in the meantime to be skeptical of this relationship. For one, the series of observations is very short and the change in values consists only of one maximum between two minima. For another, if this relation shows that strong upwelling brings about higher recruitment, we should see an agreement between values of the upwelling index and recruitment. The strong recruitments of 1980 and 1981 coincide with the highest values of the upwelling index, but this is not the case for 1978.

In order to estimate recruitment prior to 1976, recruitment obtained by cohort analysis was compared to catches of age 0 and age 1 sardines, available since 1968 (Belvèze 1972, 1981). Catches of age 0 sardine in numbers of fish, were added to catches of age 1 of the following year because in certain years, age 0 fish were incompletely recruited to the fishery.

The results are presented in Table 6 and in Figure 17. There is an evident parallelism between recruitment and catches of ages 0 and 1 in zone A. If the hypothesis that this parallelism existed before 1976 is made, the Moroccan catch of young sardines may be taken as a proportional index of recruitment.

A very important recruitment took place in 1970 while the upwelling index was slightly lower than the mean. However, from 1973 to 1975, the upwelling index remained at high values, without an increase in recruitment.

This contradiction with the preceding results imposes doubts on their validity. It is possible that the observed relation between catch and mean upwelling of the three preceding years may, in reality, only be a coincidence between two series that are too short. It is equally possible that an increase in upwelling south of zone B may attract the sardines from zone C. This hypothesis is not easily verifiable but should not be discarded *a priori* because the period of greatest catches in zone B corresponds to a period of *weakening* of the upwelling in zone C.

## Zone C

This zone, situated between 20°N and 26°N harbors a sardine population which is relatively independent of zones A and B. The zone has increased in area by the extension southward at the start of the 70's. Exploitation began in 1968, the by-catch consisting of mackerel and horse-mackerel. Catches increased considerably in several years with greater mobility and power of the exploiting fleets. In 1973, the sardine became the principal catch species of the fishery.

*Available data*. For abundance, catches are known by the declarations of fishing nations to CECAF, and are published in its statistical bulletin. Abundance in numbers and biomass in weight, obtained by cohort analysis, from 1972 to 1979 were presented at the Ad hoc Working Group on the Sardine by Domanevsky (Dakar 1980). Three estimates of biomass were made by acoustic surveys (Bazigos *et al*., 1980; Lamboeuf *et al*., 1982). These different data are presented in Table 7.

With regard to indices of upwelling, variations in upwelling were analyzed by Sedykh (1978, 1979). Ekman transport values were calculated for squares of 5 degrees for the period from 1957 to 1977. A considerable increase in the intensity of upwelling was found for the years 1971-1974, followed by a decrease in 1975-1976, and a new increase in 1977. It was estimated that the cycle of abnormally strong upwelling finished in 1978.

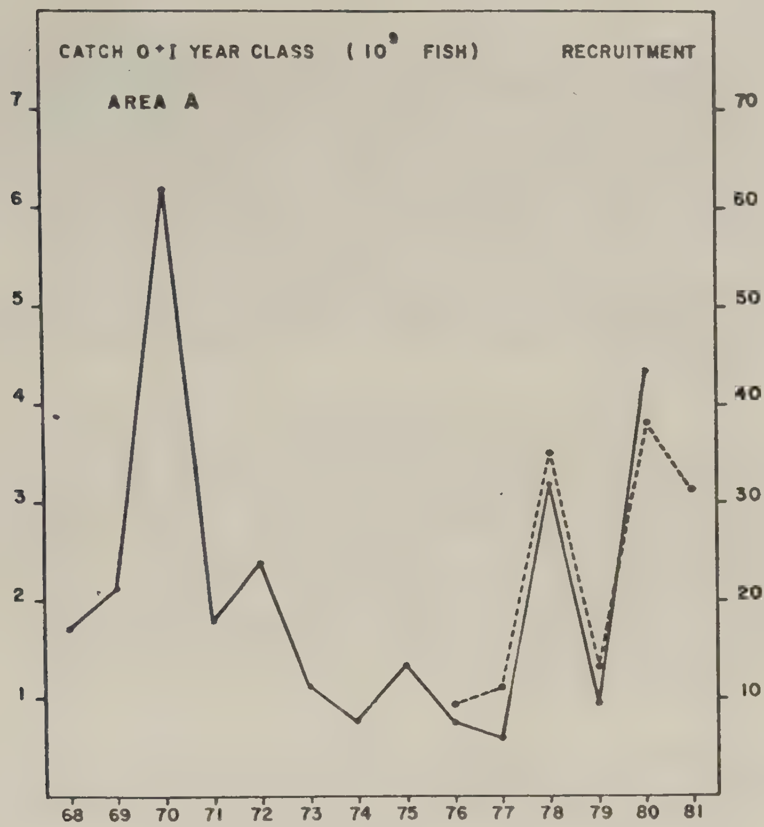


Figure Nº 17: Recruitment, calculated by cohort analysis, from 1976 to 1981 and catches of Age 0 sardines added to catches of Age 1 the following year in zone A from 1968 to 1980.

Table 6: Recruitment, Moroccan catch of age 0 and 1 for the same cohort, and annual upwelling index.

| Year | Recruitment ($10^9$ sardines) | Catch of age 0 and 1 ($10^9$ sardines) | Upwelling Index (tons/s/100m) |
|---|---|---|---|
| 1968 | - | 1.7 | 197.5 |
| 1969 | - | 2.1 | 118.3 |
| 1970 | - | 6.2 | 187.3 |
| 1971 | - | 1.8 | 168.0 |
| 1972 | - | 2.4 | 183.7 |
| 1973 | - | 1.1 | 218.8 |
| 1974 | - | 0.8 | 213.1 |
| 1975 | - | 1.3 | 223.8 |
| 1976 | 9.6 | 0.8 | 179.4 |
| 1977 | 11.4 | 0.6 | 187.2 |
| 1978 | 35.3 | 3.2 | 185.9 |
| 1979 | 13.3 | 0.9 | 175.3 |
| 1980 | 38.3 | 4.3 | 226.4 |
| 1981 | 31.5 | - | 220.3 |

Anomalies of sea surface temperatures (SST) recorded by merchant ships along the length of the northwest African coast were provided on a monthly basis for the period 1971-1981 by McLain. The usual maritime route skirts the African coast to the south of the Canary Islands, and the number of observations is highest between 27°N and 20°N (zone C). Observations are least frequent or even absent north of Cape Bojador (zones A and B). Sea surface temperature anomalies are averaged monthly for each one degree square.

Results and discussion. An annual mean was determined, weighted by the number of days of each month, on the basis of the monthly data provided by McLain. These means, from 1971 to 1981, are given in Table 8, for each one degree square for zone C. The overall mean is also given.

Variations in the annual means of SST anomalies, represented graphically in Figure 18, show that negative anomalies were more important in the southern part of the zone than in the northern part from 1972-1974. This agrees with the observations of Sedykh, and explains the extension and the development of the sardine population between 22°N and 20°N through the years 1971-1974. The strengthening of the upwelling pointed out by Sedykh also causes more important cooling of the surface waters in the southern part of the zone. Mean annual SST anomalies become strongly positive starting in 1978, which is also in accordance with Sedykh's estimate concerning the end of the period of abnormally high upwelling. Generally, the amplitudes of the variations are greater in the south than in the north.

The comparison between the upwelling indices, stock biomass and catches shows the concordance between the values of upwelling calculated by Sedykh (Ekman transport in tons per second per 100 m width) and the annual mean SST for the whole zone. Stock biomass increases with increasing upwelling intensity with a time lag of a year. This is expected if the hypothesis that upwelling acts on recruitment is correct. Catches continued to increase up to 1976 when biomass was already declining due to concentration of fishing effort of industrial fishing vessels which were attracted by high yields recorded in previous years, and were not allowed in other areas by the extension of Exclusive Economic Zones. In 1977 and 1978, catches represented a bit more than 30% of the biomass, which is a level of exploitation comparable to that of zones A and B. Starting from 1979, the exploitation rate fell to less than 20% following the closure of fishing to the north of the 24th parallel by Morocco. Nevertheless, biomass, estimated by acoustic survey, continued to decrease up till 1981. It appears that environmental conditions are the principal causes of the considerable fluctuations in sardine abundance recorded in zone C in the past six years. The level of exploitation probably accelerated the natural decline of the population, but it cannot be entirely responsible for such a change. The weakening of the upwelling starting from 1976 in the southern part of zone C, may equally have contributed to a displacement of the sardines towards the north, where the weakening was less pronounced. The acoustic surveys of 1979 to 1981 proved a gradual disappearance of sardines between 20°N and 23°N (Bazigos et al., 1980; Lamboeuf et al., 1982). It is difficult to determine whether this disappearance is linked to the concentration of effort to the south of 24°N, or to a real displacement of the sardines caused by the weakening in upwelling, as fishing is no longer authorized north of 24°N since 1979.

## CONCLUSIONS

There are two main populations of sardine (*Sardina pilchardus* Walbaum) along the northwest African coastline in areas of the continental shelf where the littoral waters are enriched by upwelling of deep water (Central North Atlantic Water of the Canary Current). The boundary between this watermass and the Central South Atlantic Water is at the level of 20° - 22°N and corresponds approximately to the boundary between the sardine and the sardinellas (*Sardinella aurita* and *S. eba*). The sardines of the north zone are the object of two separate fisheries. Fishery A, the oldest, has been traditionally exploited by artisanal Moroccan seiners. Fishery B is exploited by boats based largely in the Canary Islands. The population retreats to zone B in winter, when the greatest amount of spawning takes place, and spreads out in summer, invading zone A. The Moroccan fishing is seasonal and is subject to fluctuations in availability of the

Table 7: Abundance ($10^9$ sardines), biomass (thousands of tons), catch (thousands of tons), and catch as a proportion of biomass in zone C from 1969 to 1980.

| Year | Abundance | Biomass (a) | Biomass (b) | Catch | Catch % / Biomass |
|---|---|---|---|---|---|
| 1969 | - | - | - | 80 | - |
| 1970 | - | - | - | 89 | - |
| 1971 | - | - | - | 124 | - |
| 1972 | 58.5 | 2062 | - | 138 | 6.7 |
| 1973 | 97.9 | 3632 | - | 220 | 6.1 |
| 1974 | 105.5 | 4343 | - | 407 | 9.4 |
| 1975 | 80.9 | 3816 | - | 417 | 10.9 |
| 1976 | 52.2 | 2828 | - | 647 | 22.9 |
| 1977 | 27.4 | 1597 | - | 523 | 32.8 |
| 1978 | 12.7 | 709 | - | 222 | 31.4 |
| 1979 | 31.9 | 1188 | 1342 | 112 | 9.4 |
| 1980 | - | - | 878 | 166 | 19.2 |
| 1981 | - | - | 525 | ? | ? |

(a) Cohort analysis
(b) Acoustic survey

Table 8: Annual means of SST anomalies for squares of one degree, and overall means for zone C. (calculated from monthly data of McLain)

| Year | 26°N 14°W | 25°N 15°W | 23°N 16°W | 22°N 17°W | 21°N 17°W | 20°N 17°W | Overall mean |
|---|---|---|---|---|---|---|---|
| 1971 | - 0.52 | 0.04 | - 0.17 | - 0.02 | - 0.03 | 0.16 | - 0.09 |
| 1972 | - 0.29 | - 0.38 | - 0.47 | - 0.43 | - 0.87 | - 1.07 | - 0.59 |
| 1973 | 0.08 | - 0.04 | - 0.24 | - 0.21 | - 0.36 | - 0.56 | - 0.22 |
| 1974 | - 0.33 | - 0.54 | - 0.42 | - 0.36 | - 0.31 | - 0.25 | - 0.37 |
| 1975 | - 0.42 | - 0.37 | - 0.38 | - 0.32 | - 0.08 | - 0.02 | - 0.27 |
| 1976 | 0.30 | 0.02 | 0.47 | 0.14 | 0.14 | 0.16 | 0.21 |
| 1977 | 0.27 | - 0.08 | - 0.31 | - 0.24 | - 0.41 | - 0.69 | - 0.24 |
| 1978 | 0.10 | - 0.10 | 0.01 | 0.10 | 0.50 | 0.33 | 0.16 |
| 1979 | 0.01 | 0.11 | 0.65 | 0.63 | 0.71 | 0.80 | 0.49 |
| 1980 | 0.56 | 0.85 | 0.84 | 0.73 | 0.57 | 0.51 | 0.68 |
| 1981 | 0.26 | 0.52 | 0.04 | - 0.05 | 0.13 | 0.59 | 0.25 |

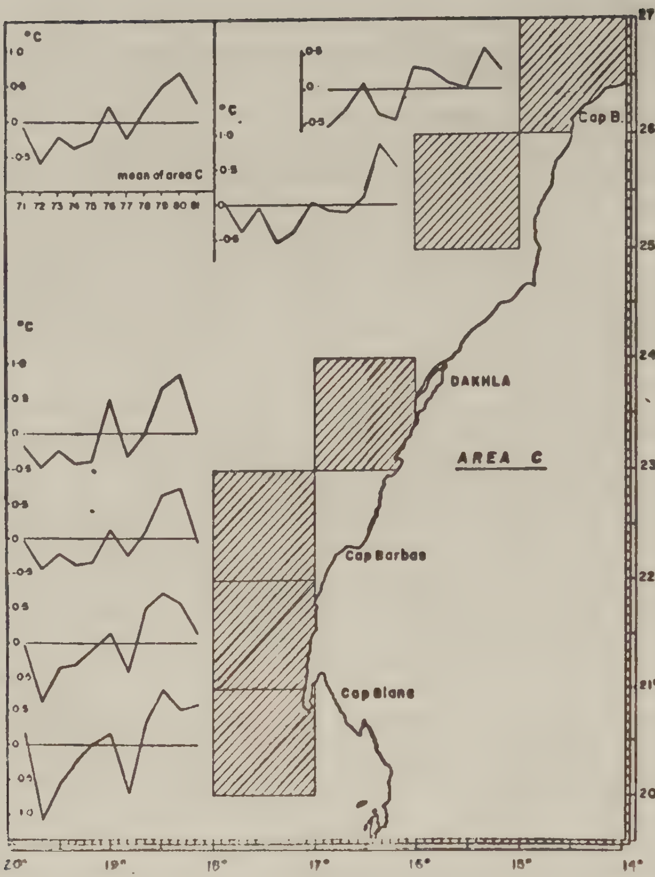
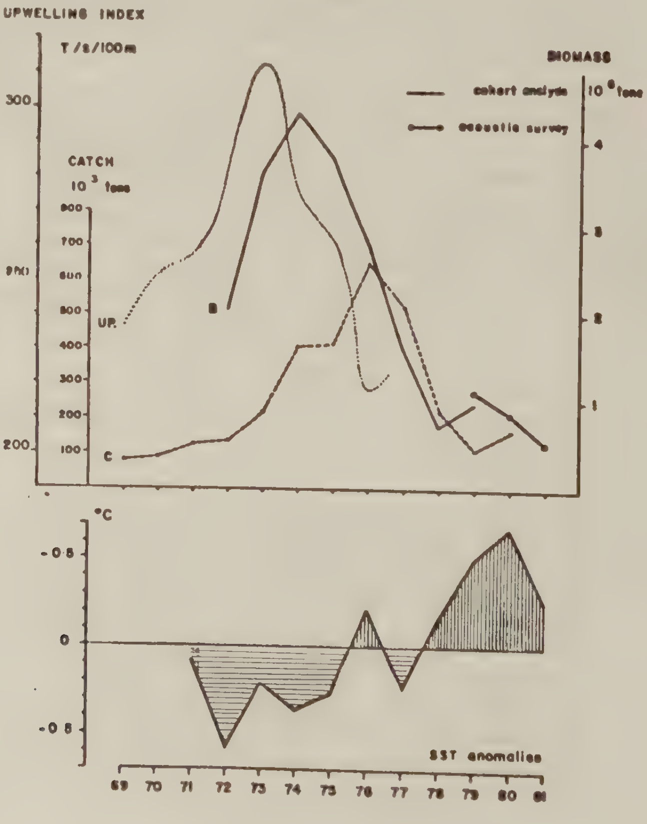

°C
1.0
0.5
0
-0.5
mean of area C
71 72 73 74 75 76 77 78 79 80 81
Cap B.
DAKHLA
AREA C
Cap Barbas
Cap Blanc
27°
26°
25°
24°
23°
22°
21°
20°
20°
19°
18°
17°
16°
15°
14°

Figure Nº 18: Changes in mean annual sea surface temperature anomalies for each square of 1 degree and for the whole of area C, calculated for 1971 to 1981 from the data of McLain.

Figure Nº 19: Comparison of catches, biomass calculated by cohort analysis and by acoustic survey, of upwelling index (from Sedykh 1979) and mean annual sea surface temperature anomalies after the data of McLain for area C.



sardine because the boats, which have only a limited sphere of action, cannot follow the sardine population in its migration. The migration from north to south is controlled by the amount of primary production between 30°N and 32°N in summer. This productivity depends on the force of the trade winds, which generate upwelling and also short-term variations in wind speed. The periods of greatest productivity occur while the winds weaken after a time of strong winds. Despite the occurrence every seven or eight years of greatly increased availability corresponding to a serious drought on the coast, the general tendency has been for a gradual weakening in the force of the trade winds, especially since 1975. To a large extent, this has been the cause of the decline of the Safi-Essaouira fishery. While the sardine remains the dominant species, it is no longer the exclusive species. With the weakening of the trade winds, the anchovy, the horse-mackerel and especially the mackerel, have been making up a bigger part of the catch. In zone B, the effect of upwelling on abundance has not been clearly shown, and there may be a mixing with the southern population between 28°N and 27°N. There is also no evidence of the relation between upwelling and availability, but in this fishery, the boats are apt to follow the sardine population along its migration. The southern population (fishery C), is found in an area of nearly year-round upwelling. It is characterized by extreme variations in abundance as well as in area occupied by the stock. Variations are well correlated with fluctuations in upwelling intensity. Since 1978, the upwelling has been weakening, and the stock has diminished considerably. Nevertheless, it seems that the high level reached in 1974, was due to abnormally strong upwelling during the preceding years, and therefore, does not represent the average size of the population.

Population studies of the sardine along the northwest African coast are recent, and the series of annual data are very short and often inadequate. It is, therefore, difficult to predict the change to come. However, if the empirical relations prove correct and the observed tendencies persist, a geographical concentration of the stocks between 24°N and 30°N, and declines of the fisheries situated at the margins of these limits, are to be expected.

This decline has important socio-economic consequences for Morocco. The principal canneries are situated at Safi and Essaouira, where numerous workers are employed. The limited sphere of action of the Moroccan sardine boats, which do not have means of on-board preservation and are small in size, means that they cannot follow the sardine migration. They are restricted to the sardines which enter their fishing area. As less and less sardines are coming in, it is necessary to take the fishing to where the fish are, i.e. zone B. There are two options open. One is to have bigger boats with refrigeration or freezing capabilities in order to bring back the fish caught south of Agadir to Safi. This would require restructuring of the fleet, and technical training of crews. The other option is to base a sizeable part of the present fleet in the new port of Tantan, at the center of zone B, and to send the catch by land to the canneries of Safi. This would require the creation of a fleet of refrigerated trucks.

Both solutions would bring about an increase in the cost price of the raw material, which would cancel the rentability of the production of preserved sardines. Productivity must also be improved by modernizing and regrouping the factories, which are too small and too numerous. This modernization scheme by regroupment and automation cannot be accomplished without a major reduction in manual labor. This would pose grave social problems for the cities of Safi and Essaouira, where the canning industry is the major means of employment.

It may be that the solution for the future is a gradual transfer of the factories to Tantan. This solution may be economically satisfactory, but would bring about the end of the fishing industry of Safi and Essaouira.

## ACKNOWLEDGEMENTS

We would particularly like to thank Dr. Andrew Bakun and Dr. Douglas McLain for kindly providing us with the results of their evaluations of the upwelling and sea surface anomalies along the northwest African coast, and also for their pertinent advice. We thank Bruno Richebē for his invaluable contribution, and Dr. Richard Parrish, whose advice guided our study during his visit to Morocco.

APPENDIX I : Rainfall in the areas of Safi/Essaouira and Agadir.
(Amount of rainfall in millimeters).

| Year | Agadir | Safi+Essaouira | Total. |
|---|---|---|---|
| 1936 | 331 | (773) | (1104) |
| 1937 | 179 | (531) | (710) |
| 1938 | 201 | (566) | (567) |
| 1939 | 344 | (793) | (1137) |
| 1940 | 327 | (766) | (1093) |
| 1941 | 281 | (693) | (974) |
| 1942 | 387 | (862) | (1249) |
| 1943 | 253 | (649) | (902) |
| 1944 | 123 | (442) | (565) |
| 1945 | 149 | (483) | (632) |
| 1946 | 213 | (585) | (798) |
| 1947 | 309 | (738) | (1047) |
| 1948 | 227 | (607) | (834) |
| 1949 | 228 | (609) | (837) |
| 1950 | 120 | (496) | (557) |
| 1951 | 141 | (471) | (612) |
| 1952 | 147 | (480) | (627) |
| 1953 | 430 | (930) | (1360) |
| 1954 | 244 | (634) | (878) |
| 1955 | 226 | 829 | 1055 |
| 1956 | 387 | 712 | 1099 |
| 1957 | 160 | 644 | 804 |
| 1958 | 110 | 459 | 569 |
| 1959 | 117 | 533 | 650 |
| 1960 | 181 | 611 | 792 |
| 1961 | 127 | 492 | 619 |
| 1962 | 248 | 721 | 969 |
| 1963 | 670 | 1039 | 1709 |
| 1964 | 286 | 726 | 1012 |
| 1965 | 224 | 578 | 802 |
| 1966 | 179 | 383 | 562 |
| 1967 | 430 | 917 | 1347 |
| 1968 | 365 | 799 | 1164 |
| 1969 | 267 | 961 | 1228 |
| 1970 | 361 | 698 | 1059 |
| 1971 | 195 | 748 | 943 |
| 1972 | 243 | 815 | 1058 |
| 1973 | 123 | 462 | 585 |
| 1974 | 175 | 419 | 594 |
| 1975 | 121 | 440 | 561 |
| 1976 | 195 | 724 | 919 |
| 1977 | 294 | 748 | 1042 |
| 1978 | 233 | 458 | 691 |
| 1979 | 230 | 454 | 684 |
| 1980 | 290 | 469 | 711 |
| 1981 | 138 | 267 | 405 |

Values between parentheses were estimated from data recorded at Agadir.

Appendix II : Catches of small coastal pelagics between 32°30'N and 29° N (Zone A) by Moroccan seiners.

| Year | Total | SARDINE | | Mackerel | | Horse-mackerel | | Anchovy | |
|---|---|---|---|---|---|---|---|---|---|
| | Tons | Tons | % | Tons | % | Tons | % | Tons | % |
| 1960 | 94 563 | 87 018 | 92.0 | 7 246 | 7.7 | 186 | 0.2 | 113 | 0.1 |
| 1961 | 129 288 | 120 226 | 93.0 | 8 678 | 6.7 | 265 | 0.2 | 119 | 0.1 |
| 1962 | 130 438 | 120 136 | 92.1 | 9.111 | 7.0 | 194 | 0.1 | 997 | 0.8 |
| 1963 | 131 971 | 119 128 | 90.3 | 12.494 | 9.5 | 209 | 0.2 | 140 | 0.1 |
| 1964 | 137 119 | 130 392 | 95.1 | 6.112 | 4.5 | 349 | 0.3 | 266 | 0.2 |
| 1965 | 157 996 | 148 457 | 94.0 | 9.006 | 5.7 | 318 | 0.2 | 215 | 0.1 |
| 1966 | 243 235 | 237 657 | 97.7 | 5.117 | 2.1 | 292 | 0.1 | 109 | 0.0 |
| 1967 | 204 689 | 196 597 | 96.0 | 7 704 | 3.8 | 343 | 0.2 | 45 | 0.0 |
| 1968 | 161 698 | 155 397 | 96.1 | 5.182 | 2.2 | 847 | 0.5 | 172 | 0.0 |
| 1969 | 166 514 | 157 168 | 94.4 | 8 189 | 4.9 | 915 | 0.5 | 242 | 0.1 |
| 1970 | 182 328 | 150 233 | 82.4 | 26 429 | 14.5 | 1382 | 0.8 | 4 284 | 2.3 |
| 1971 | 182 322 | 172 676 | 94.7 | 7 438 | 4.1 | 655 | 0.4 | 1 553 | 0.9 |
| 1972 | 166 102 | 159 211 | 95.9 | 4 288 | 2.6 | 1304 | 0.8 | 1 302 | 0.8 |
| 1973 | 366 697 | 326 261 | 96.9 | 8 280 | 2.5 | 1579 | 0.5 | 576 | 0.2 |
| 1974 | 228 217 | 204 231 | 89.5 | 21 222 | 9.3 | 611 | 0.3 | 2 153 | 0.9 |
| 1975 | 161 385 | 146 614 | 90.8 | 12 279 | 7.6 | 2255 | 1.4 | 237 | 0.1 |
| 1976 | 210 284 | 176 162 | 83.8 | 26 161 | 12.4 | 7584 | 3.6 | 377 | 0.2 |
| 1977 | 186 892 | 101 877 | 54.5 | 47.573 | 25.5 | 33406 | 17.9 | 4 036 | 2.2 |
| 1978 | 186 759 | 91 141 | 48.8 | 47 610 | 25.5 | 47402 | 25.4 | 606 | 0.3 |
| 1979 | 192 730 | 163 442 | 84.8 | 15.676 | 8.1 | 13016 | 6.8 | 596 | 0.3 |
| 1980 | 222 704 | 181 198 | 81.4 | 31.375 | 14.2 | 9246 | 4.2 | 685 | 0.3 |
| 1981 | 240 019 | 200 395 | 83.5 | 30.362 | 12.6 | 8743 | 3.6 | 519 | 0.2 |
| 1982 | 166 204 | 104 738 | 63.0 | 55.185 | 33.2 | 4856 | 2.9 | 1425 | 0.9 |

Appendix III : Deviations as percentages, of observed values of rainfall and of catch with respect to a 9 year running mean.

| Year | Δ % Catch | Δ % Rainfall. |
|---|---|---|
| 1948 | - 35.5 | + 15.2 |
| 1949 | + 16.3 | + 3.1 |
| 1950 | + 53.5 | - 33.6 |
| 1951 | - 6.4 | - 29.4 |
| 1952 | + 25.4 | - 28.2 |
| 1953 | + 16.6 | + 56.3 |
| 1954 | - 19.8 | + 4.5 |
| 1955 | - 35.7 | + 24.1 |
| 1956 | - 13.1 | + 26.3 |
| 1957 | - 11.2 | - 7.5 |
| 1958 | + 23.3 | - 31.1 |
| 1959 | - 2.3 | - 29.2 |
| 1960 | - 17.9 | - 13.3 |
| 1961 | + 4.4 | - 29.7 |
| 1962 | - 6.2 | + 13.5 |
| 1963 | - 10.9 | + 81.8 |
| 1964 | - 11.3 | + 1.5 |
| 1965 | - 2.9 | - 23.3 |
| 1966 | + 44.5 | - 48.7 |
| 1967 | + 17.5 | + 23.4 |
| 1968 | - 9.2 | + 14.2 |
| 1969 | - 16.8 | + 26.3 |
| 1970 | - 12.1 | + 11.6 |
| 1971 | - 8.1 | + 0.6 |
| 1972 | - 15.9 | + 17.4 |
| 1973 | + 68.8 | - 34.1 |
| 1974 | + 11.0 | - 28.3 |
| 1975 | - 20.5 | - 28.7 |
| 1976 | - 3.6 | + 20.8 |
| 1977 | - 16.0 | + 51.5 |

## Appendix IV. : Mean annual wind speed, variance, and azimuth of the wind at Essaouira from 1945 to 1980 (after Richebé).

| Year | Mean speed (m/s) | Variance (m/s) | Azimuth (degrees). |
|---|---|---|---|
| 1945 | 4.98 | 4.82 | 348° |
| 1946 | 4.79 | 5.67 | 360° |
| 1947 | 5.34 | 9.68 | 12° |
| 1948 | 4.67 | 9.24 | 6° |
| 1949 | 5.85 | 9.81 | 18° |
| 1950 | 7.01 | 8.16 | 10° |
| 1951 | 5.12 | 3.54 | 355° |
| 1952 | 5.69 | 3.57 | 20° |
| 1953 | 6.50 | 4.44 | 4° |
| 1954 | 6.17 | 3.89 | 352° |
| 1955 | 5.03 | 4.92 | 343° |
| 1956 | 4.49 | 2.36 | 12° |
| 1957 | 4.30 | 1.91 | 6° |
| 1958 | 5.56 | 2.65 | 13° |
| 1959 | 5.00 | 3.29 | 4° |
| 1960 | 4.96 | 2.26 | 11° |
| 1961 | 4.78 | 3.19 | 51° |
| 1962 | 4.95 | 3.45 | 12° |
| 1963 | 4.78 | 1.68 | 14° |
| 1964 | 4.09 | 1.40 | 7° |
| 1965 | 5.21 | 2.09 | 48° |
| 1966 | 5.03 | 3.22 | 59° |
| 1967 | 4.92 | 1.63 | 40° |
| 1968 | 4.77 | 1.57 | 28° |
| 1969 | 4.70 | 2.10 | 16° |
| 1970 | 4.44 | 2.28 | 13° |
| 1971 | 4.29 | 2.31 | 12° |
| 1972 | 4.30 | 1.65 | 351° |
| 1973 | 4.87 | 4.33 | 18° |
| 1974 | 5.18 | 2.38 | 33° |
| 1975 | 3.31 | 2.25 | 17° |
| 1976 | 2.55 | 1.26 | 44° |
| 1977 | 2.65 | 2.53 | 30° |
| 1978 | 2.94 | 1.96 | 21° |
| 1979 | 2.63 | 1.99 | 33° |
| 1980 | 2.77 | 2.25 | 27° |

Appendix V. : Annual means of the Upwelling index calculated by Bakun for 28°N,13°W, deviations from the overall mean, and monthly and trimesterly means in tons/s/100m.

| Year | Upwelling Index | Deviation from the mean |
|---|---|---|
| 1946 | 136.5 | - 24.3 |
| 1947 | 90.0 | - 70.9 |
| 1948 | 115.9 | - 45.0 |
| 1949 | 105.7 | - 55.2 |
| 1950 | 145.0 | - 15.9 |
| 1951 | 154.5 | - 6.4 |
| 1952 | 159.5 | - 1.4 |
| 1953 | 134.0 | - 26.9 |
| 1954 | 229.3 | + 68.4 |
| 1955 | 118.2 | - 42.7 |
| 1956 | 134.4 | - 26.5 |
| 1957 | 78.0 | - 82.9 |
| 1958 | 76.6 | - 84.3 |
| 1959 | 88.4 | - 72.5 |
| 1960 | 237.3 | + 76.4 |
| 1961 | 221.4 | + 60.5 |
| 1962 | 178.9 | + 18.0 |
| 1963 | 86.3 | - 74.6 |
| 1964 | 129.3 | - 31.5 |
| 1965 | 153.6 | - 7.2 |
| 1966 | 166.1 | + 5.2 |
| 1967 | 167.5 | + 6.6 |
| 1968 | 197.5 | + 36.6 |
| 1969 | 118.3 | - 42.6 |
| 1970 | 187.3 | + 26.4 |
| 1971 | 168.0 | + 7.1 |
| 1972 | 183.7 | + 22.8 |
| 1973 | 218.8 | + 57.9 |
| 1974 | 213.1 | + 52.2 |
| 1975 | 223.8 | + 62.9 |
| 1976 | 179.4 | + 18.5 |
| 1977 | 187.2 | + 26.9 |
| 1978 | 185.9 | + 25.0 |
| 1979 | 175.3 | + 14.4 |
| 1980 | 226.4 | + 65.6 |
| 1981 | 220.3 | + 59.4 |

overall (general) mean : 160.9

Trimesterly means

| | |
|---|---|
| Ier | 60.5 |
| 2èm | 209.I |
| 3èm | 305.6 |
| 4èm | 66.8 |

Monthly means

| | |
|---|---|
| J | - 47.5 |
| F | - 54.7 |
| M | - 78.7 |
| A | -149.2 |
| M | -204.I |
| J | -274.I |
| J | -381.6 |
| A | -334.8 |
| S | -196.8 |
| O | - 88.7 |
| N | - 54.6 |
| D | - 56.7 |

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*SOUTH EAST ATLANTIC - ATLANTICO SUDORIENTAL*

# ASSESSMENT AND MANAGEMENT OF PELAGIC STOCKS IN THE SOUTHERN BENGUELA REGION

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## Resumen

Se examina la evaluación y ordenación de las pesquerías pelágicas frente a Sudáfrica (SA) y Namibia, con particular referencia a la sardina *Sardinops ocellata* y anchoveta *Engraulis capensis* que son los mayores componentes de las capturas.

Ambas pesquerías fueron dominadas inicialmente por la Sardina, cuyos stocks colapsaron después que las capturas alcanzaron un máximo de 400 mil toneladas en SA en 1962, y 1 400 miles de toneladas en Namibia en 1968. Aun cuando el stock de Namibia mostró una recuperación parcial a mediados de los años 1970s, ambos stocks actualmente parecen estar seriamente reducidos, cada uno con una biomasa menor de 100 mil toneladas.

La anchoveta se ha convertido en el mayor componente en ambas pesquerías. En Namibia el stock y los desembarques son altamente variables, y hay considerable inquietud acerca del estado de los stocks de sardina y anchovetas después de los pobres reclutamientos en 1982. En SA el stock de anchoveta parece ser más estable, pero con una participación decreciente de sardina, caballa y jurel en los desembarques anuales, hay indicaciones que el aumento de la presión sobre anchoveta puede conducir a la sobreexplotación.

El principal mecanismo de ordenación de la pesca ha sido el establecimiento de cuotas anuales para cada especie separadamente, o una cuota global para todas las especies combinadas. Las restricciones se formularon intuitivamente hasta inicios de los años 1970s, cuando se hicieron las primeras estimaciones cuantitativas. Para SA, la recomendación inicial de una cuota global de 360 mil toneladas fue basada en el modelo de producción de Shaefer. Análisis subsiguientes indican que una cifra 325 mil toneladas era más adecuada en vista de la desaparición virtual de algunas especies en los desembarques, sin embargo, las autoridades mantuvieron las cuotas en 380 mil toneladas durante los últimos cinco años.

En Namibia, durante la recuperación parcial del stock a inicios de los años 1970s, las cuotas de sardina se ajustaron empíricamente tomando como base principal los resultados de reconocimientos aéreos. La imposibilidad de detectar la pobreza del reclutamiento a tiempo como para poder reducir consecuentemente las cuotas para los períodos subsiguientes, durante los cuales no se hicieron reconocimientos, llevaron a un nuevo colapso del stock. Actualmente la ordenación de la pesca de sardina se basa en proyecciones a partir del Análisis de Población Virtual (VPA), y en la aplicación de restricciones del tamaño de malla de las redes, y de las áreas y temporadas de pesca, además de la instalación de sistemas de agua de mar refrigerada para que, en la medida de lo posible, la sardina que se captura sea utilizada sólo para enlatado y se evita la captura incidental de sardina con anchoveta juvenil.

El rendimiento promedio anual de 200 mil toneladas de anchoveta para Namibia se considera adecuado, esencialmente en base a la performance histórica, pero la cuota es modificada anualmente en base a reconomientos de huevos que se hacen antes de la temporada de pesca, y a indicaciones de la fuerza del reclutamiento en ese año.

Se discuten los métodos de evaluación que se han utilizado o que están siendo empleados para estos stocks, así como los problemas encontrados. Estos métodos son VPA, captura por unidad de esfuerzo, reconocimiento de huevos, reconocimientos aéreos y acústicos, marcación, además del estudio de sedimentos y registros de depósitos de guano, los que dan alguna información sobre la tendencia de los stocks antes que se iniciara la pesquería. Hay algunas indicaciones de un fuerte comportamiento dependiente de la densidad en algunos de los stocks.

No hay respuesta a la pregunta de si las pesquerías de SA y Namibia explotan los mismos stocks o stocks independientes, lo cual tiene importancia para la ordenación, en particular la anchoveta de Namibia.

Ambas pesquerías de anchoveta dependen fuertemente de los reclutamientos de ese año (más del 95% del número de anchovetas capturadas en Namibia en años recientes han sido del grupo edad 0). Lo que más se necesita para fines de ordenación son métodos que puedan determinar a tiempo las fallas del reclutamiento. En principio, los reconocimientos hidroacústicos parecen ofrecer las mejores perspectivas, pero todavía no se ha determinado si la varianza de los estimados será lo suficientemente pequeña como para permitir un impacto efectivo en la ordenación, tanto desde el punto de vista teórico como práctico.

Las principales lecciones de las pesquerías sudáfricanas son:

i) la necesidad de determinar la edad de las especies desembarcadas en forma regular y exacta para una correcta interpretación de las tendencias de los stocks

ii) la necesidad de métodos de reconocimientos de evaluación de los stocks que no sean afectados por los sesgos de las muestras de la pesquería, en particular para poder detectar a timepo las disminuciones de los stocks

iii) las regulaciones deben ser simples y factibles de ser puestas en vigor; aun cuando la fijación de cuotas para cada especie puede ser deseable desde el punto de vista biológico, las violaciones y perjuicios potenciales tales como desperdicio de captura y fallas en la identificación de las especies pueden hacer que una cuota global combinada posiblemente con cierre de algunas áreas sea una medida más realística y práctica

iv) en el proceso de toma de decisiones para el ordenamiento de la pesca se debe contrapesar la actitud excesivamente optimista de la industria que presiona para mantener o incrementar las cuotas para asegurar ganancias a corto plazo (o, en algunos casos, para sobrevivir); la poca representación científica a este nivel en Sudáfrica ha hecho que los científicos jueguen un papel no del todo efectivo de acción de retroguardia en su capacidad de proteccionistas, en lugar de desempeñar el rol que les corresponde como asesores imparciales para lograr la utilización a largo plazo de los recursos pesqueros.

## INTRODUCTION

There are numbers of previous reviews of the pelagic fisheries of South Africa (SA) (Cram, 1977; Newman et al., 1979; and Crawford, 1979 ) and Namibia/South West Africa (SWA/N) (Cram, 1977; Troadec et al., 1980 ; Cram, 1981 ). ICSEAF Collections of Scientific Papers for recent years also contain regularly updated assessments of the major stocks.

This paper will not attempt as comprehensive a review of the earlier periods of these fisheries as in the above, but will rather concentrate on more recent initiatives in assessment and management. Further only the pilchard *(Sardinops ocellata)* and anchovy (*Engraulis capensis*), the major contributors to these fisheries, will be considered.

Management of South African fisheries is in terms of the Sea Fisheries Act (1973) which empowers the Minister (previously of Economic Affairs, then Agriculture and Fisheries, and now Environment Affairs and Fisheries) to regulate any aspect of the fishing industry. The Minister receives scientific advice from the Sea Fisheries Research Institute of the Department of Environment Affairs and Fisheries, which has statutory responsibility for conducting research into marine fisheries. Separate Fisheries Advisory Councils exist for the two fisheries to make management recommendations to the Minister; these bodies consist mainly of Industry representatives, but include the Director of the Sea Fisheries Research Institute. Since 1978 the Minister's powers for the SWA/N fishery have been transferred to local authorities.

The paper first traces the history of the SA and SWA/N pilchard and anchovy fisheries and the associated management policies. The various stock assessment techniques that have been used are commented upon, together with indications of the present status of the stocks and future research priorities. Economic aspects of the two fisheries are discussed briefly, and a concluding section discusses what the author considers the major lessons to be learnt from the history of these fisheries regarding stock assessment and management.

## HISTORY AND MANAGEMENT PRACTICE

### South African Fishery

Although pilchards were first canned in SA in 1935, major development of the pelagic fishery commenced only after the war. Fishing is confined mainly to the area between latitude 31°S and longitude 21°E (see Fig. 1), and generally occurs close to the coast (about 20 km). This area is concurrently served by 6 fishing harbours and 10 processing plants.

Annual landings by species are shown in Table 1 and Fig. 2. The early stages of the fishery were dominated by pilchard and horse mackerel (*Trachurus trachurus*). Pilchard catches rose markedly in the late 1950's, but a decline set in from 1963. To compensate for this decline, small mesh nets (see Table 2) were introduced to allow exploitation of anchovy, with these nets becoming universally used from 1965. From mid 1960's to mid 1970's, though anchovy became the major contributor, chub mackerel (*Scomber japonicus*) and (on occasions) pilchard made substantial contributions. Over the last four years, anchovy has dominated comprising some 80% of the total landings.

Table 2 lists a number of the restrictions applied by management to the fishery. Limitations on processing capacity to prevent over-investment have been in force since 1950. Various closed seasons have been operative since 1951, primarily over the spring months. Motivation for these has been to avoid fishing during the spawning season (September to March for pilchard; November to March for anchovy (Davies et al., 1981; Crawford, 1981a; b ); also the oil yield from the fish which is important economically, is low over this period. The closed seasons also serve to restrict effort.

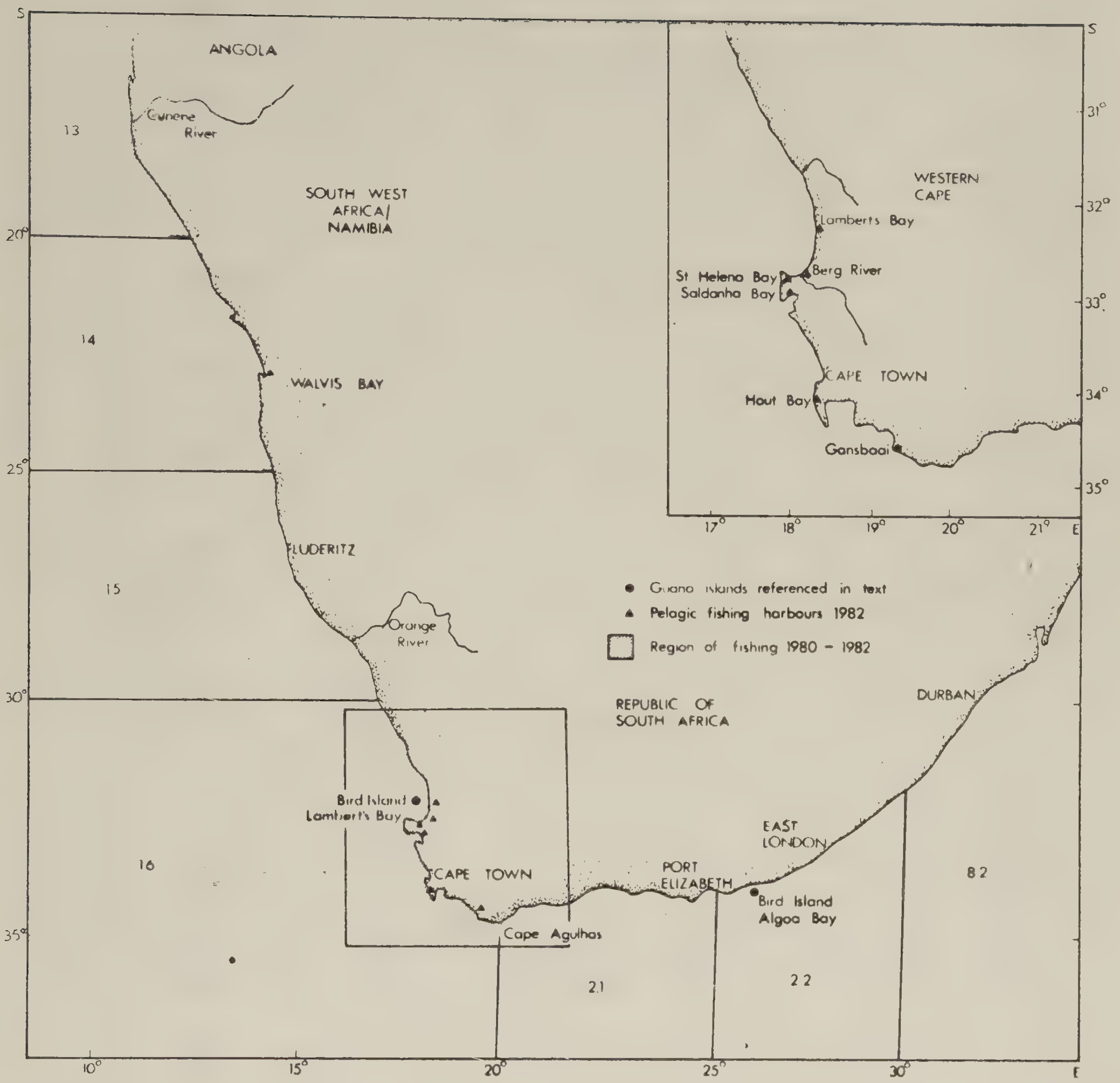
ANGOLA
Cunene River
13
SOUTH WEST AFRICA/ NAMIBIA
14
WALVIS BAY
15
LUDERITZ
Orange River
16
Bird Island
Lambert's Bay
CAPE TOWN
Cape Agulhas
REPUBLIC OF SOUTH AFRICA
PORT ELIZABETH
EAST LONDON
DURBAN
Bird Island Algoa Bay
2.1
2.2
8.2
● Guano islands referenced in text
▲ Pelagic fishing harbours 1982
☐ Region of fishing 1980 – 1982
WESTERN CAPE
Lamberts Bay
Berg River
St Helena Bay
Saldanha Bay
CAPE TOWN
Hout Bay
Gansbaai
S
E
10°
15°
20°
25°
30°
35°
17°
18°
19°
20°
21°
31°
32°
33°
34°
35°

Fig. 1. The Southern Benguela Region showing the areas of pelagic fishing, the harbours from which the fishing fleets operate, and two guano islands referenced in the text. Oceanic divisions indicated are according to ICSEAF conventions.

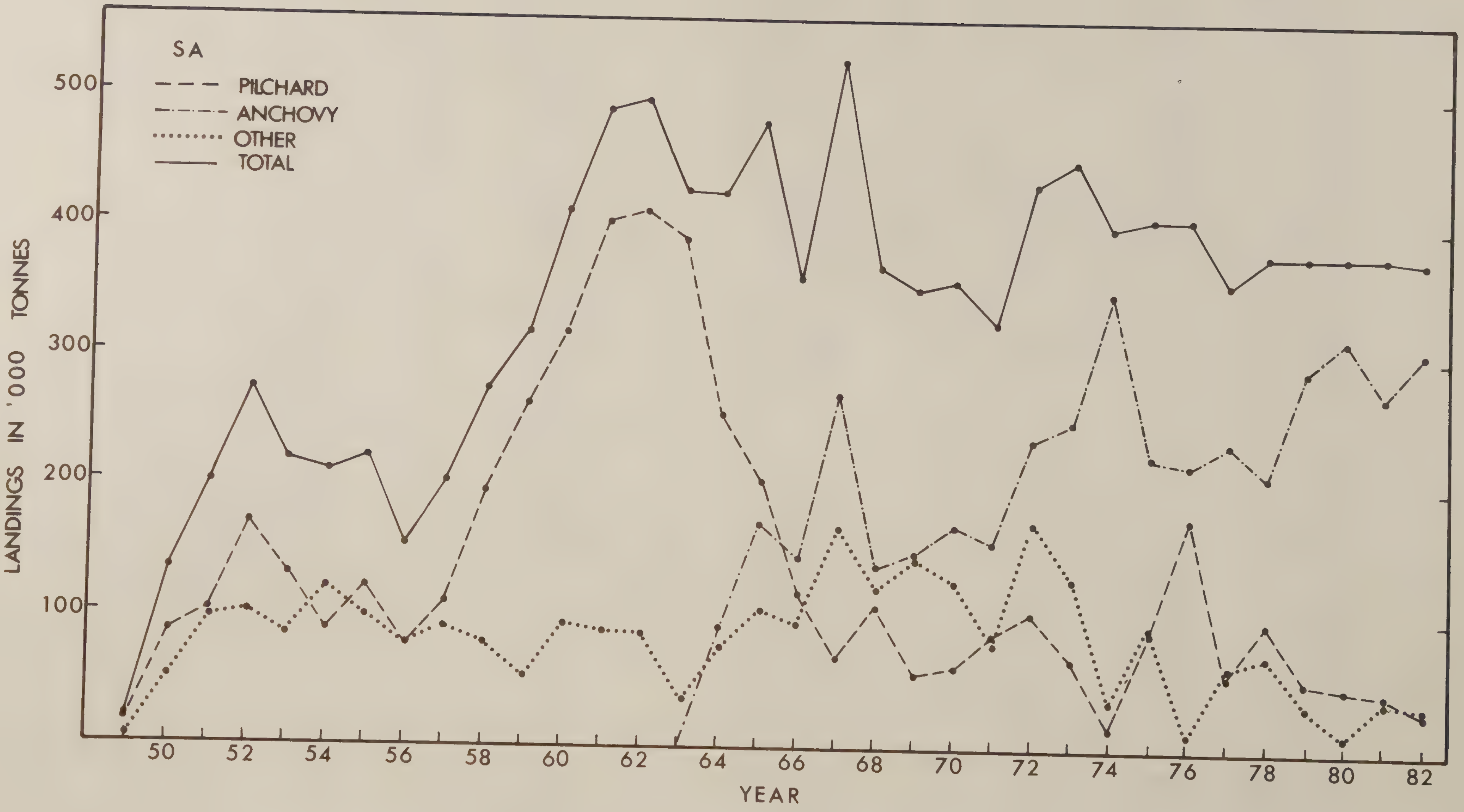

Fig. 2. Total annual landings, and landings per species in the SA pelagic fishery 1949-1982.

Table 1: Species composition of South African purse seine landings ('000 t), 1949-1982.

| Year | Pilchard | Anchovy | Horse mackerel | Chub mackerel | Round herring | Lantern-fish | Total |
|---|---|---|---|---|---|---|---|
| 1949 | 17 | - | 3 | - | - | - | 21 |
| 1950 | 85 | - | 50 | - | - | - | 135 |
| 1951 | 102 | - | 99 | - | - | - | 200 |
| 1952 | 170 | - | 103 | - | - | - | 273 |
| 1953 | 133 | - | 85 | - | - | - | 218 |
| 1954 | 88 | - | 118 | 4 | - | - | 211 |
| 1955 | 122 | - | 79 | 20 | - | - | 221 |
| 1956 | 77 | - | 46 | 33 | - | - | 155 |
| 1957 | 110 | - | 85 | 7 | - | - | 202 |
| 1958 | 194 | 0 | 56 | 22 | 1 | - | 273 |
| 1959 | 260 | 1 | 18 | 33 | 2 | - | 315 |
| 1960 | 318 | - | 63 | 31 | 0 | - | 412 |
| 1961 | 402 | - | 39 | 50 | 0 | - | 491 |
| 1962 | 410 | - | 67 | 20 | 0 | - | 497 |
| 1963 | 390 | 0 | 23 | 13 | 0 | - | 427 |
| 1964 | 256 | 92 | 24 | 50 | 3 | - | 426 |
| 1965 | 205 | 171 | 55 | 41 | 8 | - | 480 |
| 1966 | 118 | 144 | 26 | 53 | 15 | - | 357 |
| 1967 | 70 | 271 | 9 | 128 | 32 | - | 509 |
| 1968 | 108 | 138 | 1 | 91 | 30 | 0 | 369 |
| 1969 | 56 | 149 | 27 | 92 | 23 | 5 | 352 |
| 1970 | 62 | 169 | 8 | 78 | 24 | 18 | 358 |
| 1971 | 88 | 157 | 2 | 54 | 22 | 2 | 325 |
| 1972 | 104 | 236 | 1 | 57 | 21 | 15 | 434 |
| 1973 | 69 | 251 | 2 | 59 | 29 | 42 | 451 |
| 1974 | 16 | 350 | 3 | 31 | 1 | 0 | 401 |
| 1975 | 89 | 224 | 2 | 69 | 24 | 0 | 407 |
| 1976 | 176 | 218 | 0 | 1 | 12 | 0 | 408 |
| 1977 | 58 | 236 | 2 | 21 | 35 | 6 | 357 |
| 1978 | 97 | 210 | 4 | 2 | 67 | 1 | 380 |
| 1979 | 53 | 291 | 4 | 3 | 21 | 9 | 381 |
| 1980 | 50 | 316 | 0 | 0 | 14 | 0 | 381 |
| 1981 | 46 | 292 | 6 | 0 | 24 | 10 | 379 |
| 1982 | 34 | 307 | 1 | 3 | 31 | 1 | 376 |

Table 2: Management restrictions for the SA purse seine fishery 1943-1982

| Year | Closed Season | | Minimum Net Mesh Size (mm) | Quotas ('000 tonnes) | |
|---|---|---|---|---|---|
| | | | | Pilchard and Horse Mackerel | Global (All Species) |
| 1943-49 | - | | - | - | |
| 1950 | - | | 38 | - | |
| 1951 | Pilchard | 1/9-31/10 | 38 | - | |
| 1952 | Pilchard/Horse mackerel | 1/9-31/10 | 38 | - | |
| 1953 | Pilchard/Horse mackerel | 1/10-31/12 | 38 | 226.9 | |
| 1954 | Pilchard/Horse mackerel | 1/9-31/10 | 38 | 226.9 | |
| 1955 | - | | 38 | 226.9 | |
| 1956 | - | | 32 | 226.9 | |
| 1957 | - | | 32 | 226.9 | |
| 1958 | Pilchard/Horse mackerel | 1/9-31/12 | 32 | 226.9 | |
| 1959 | Pilchard/Horse mackerel | 15/8-31/12 | 32 | 226.9 | |
| 1960-62 | Pilchard | 1/8-31/12 | 32 | - | |
| | Horse/Chub mackerel | 1/8-31/10 | | | |
| 1963 | Pilchard | 1/8-31/12 | 32 | - | |
| | Horse/Chub mackerel | 1/8-31/10 | | | |
| | Anchovy | 1/1-31/8 | 12.7 (6 vessels) | | |
| 1964 | Pilchard/Round herring | 1/8-31/12 | 32; 12.7 (48 vessels) | - | |
| | Horse/Chub mackerel | 1/8-31/10 | | | |
| 1965 | Pilchard/Round herring | 1/8-31/12 | 12.7 (all vessels) | - | |
| | Horse/Chub mackerel | 1/8-31/10 | | | |
| 1966 | | 1/10-31/12 | 12.7 | - | |
| 1967 | | 1/10-31/12 | 12.7 | - | |
| 1968 | | 16/9-31/12 | 12.7 | - | |
| 1969 | | 1/9-31/12 | 12.7 | - | |
| 1970 | | 1/9-31/12 | 12.7 | - | |
| 1971 | Chub mackerel | 1/10-31/12 | 12.7 | | 362.9 |
| | Other species | 1/9-31/12 | | | |
| 1972 | | 5/8-31/12 | 12.7 | | 453.6 |
| 1973 | Chub mackerel | 1/10-31/12 | 32 (6/6-30/9) | | (Chub mackerel-) |
| | Other species | 1/9-31/12 | 12.7 | | 430 |
| 1974 | Chub mackerel | 1/10-31/12 | 32 (26/6-30/9) | | (Chub mackerel 50) |
| | Other species | 1/9-31/12 | 12.7 | | 400 |
| 1975 | | 1/9-31/12 | 12.7 | | 406 |
| 1976 | | 1/9-31/12 | 12.7 | | 407 |
| 1977 | | 1/9-31/12 | 12.7 | | 360 |
| 1978 | | 1/9-31/12 | 12.7 | | 380 |
| 1979 | | 1/9-31/12 | 12.7 | | 380 |
| 1980 | | 1/9-31/12 | 12.7 | | 380 |
| 1981 | | 1/9-31/12 | 12.7 | | 380 |
| 1982 | | 1/9-31/12 | 12.7 | | 380 |

Notes: i) Mesh of 38 mm used prior to 1956 rapidly shrank to about 32 mm. Synthetic nets used thereafter did not shrink.

ii) Chub mackerel quotas indicated for 1973-75 applied only from a date in June to end of September.

Data: 1943-1976 Crawford (1981c).

A quota for pilchard and horse mackerel was imposed in 1953, but rather flexibly applied until 1959, when it was considered too restrictive and dropped. Limitations on vessel capacity were introduced, but had little effect in curbing overall growth in the fleet hold capacity (Fig. 3a). In 1971 a global (all species) quota was reintroduced.

Prior to 1974 no quantitative assessment of sustainable yield of the fishery had been carried out; the basis for quotas was entirely intuitive, but "probably curtailed gross abuse of the stocks" (Newman and Crawford, 1980 ). Newman et al. (1974), following a power factor analysis for fishing vessels, regressed CPUE against effort (Schaefer model) to obtain a combined species MSY estimate of 360 thousand tonnes. Quotas were reduced to this level in 1977 but increased to 380 thousand tonnes the following year where they have remained since.

More recently, following an analysis by Crawford (1979), scientific recommendation has been to reduce the global quota to 325 thousand tonnes. Crawford's calculations using current effort levels and recruitment levels the average of those from 1964-1976, indicated a combined species catch of 375 thousand tonnes would eventuate. However, he recommended quota reduction to 325 thousand tonnes on the basis of effective disappearance of horse and chub mackerel from the catch. Crawford also noted that the smaller mesh net used since 1965 resulted in a poorer yield per recruit from pilchard, round herring and mackerel, and recommended attempts to avoid catching juveniles of these species.

The philosophy of a global quota is not based on a belief of a combined species carrying capacity. Rather it was felt that with a large number of species contributing to the landings, this provided some insurance against adverse fluctuations in the stock of a particular species (assuming fluctuations of the different stocks occur independently).

Until recently, major scientific concern was to reduce fishing pressure (in part through quota reduction) on the commercially more valuable pilchard resource to promote its recovery. However, over the past four years the global quota has been achieved only through increasing the anchovy contribution to 300 thousand tonnes, and concern is now growing that this species may be under threat of over-exploitation.

Egg surveys have indicated that the major anchovy (and pilchard) spawning areas are in the south in the Cape Agulhas area, and it is believed that eggs and larvae are transported northwards, with recruitment occurring from the area north of Lamberts Bay, and the fish migrating from there back to the southern areas (Crawford et al., 1980; Shelton and Hutchings, 1982).

Primarily juvenile anchovy are caught in the northern areas, principally in the autumn-winter months, with a greater proportion of adults from more southerly areas. 0-year old anchovy make up a considerable proportion of the anchovy catch (see Fig. 4), and it is evident that the fishery is potentially very vulnerable to anchovy recruitment failure.

The SA fishery initially rose to deliver landings of some 400 thousand tons on the basis of strong pilchard recruitment in the late 1950's (see Fig. 6a). Newman and Crawford (1980) pointed out that on the basis of historic indices (see subsequent section) such high recruitment occurs infrequently, and this frequency may be further depressed by the spawning biomass decrements induced by the fishery.

The fishery has subsequently followed the classical pattern of moving from more to less valuable species to maintain the total catch. With anchovy now dominant, the multi-species "safety net" seems no longer available, and a less stable fishery in the future may be indicated.

It is interesting to note that despite continuous scientific advice towards greater caution, perhaps the most significant management restrictions - the reimposition of a quota in 1971, and its decrease in 1977 - correspond to the two collapse periods of the neighbouring SWA/N pilchard resource, which presumably engendered a more safety-conscious attitude in the SA management authority.

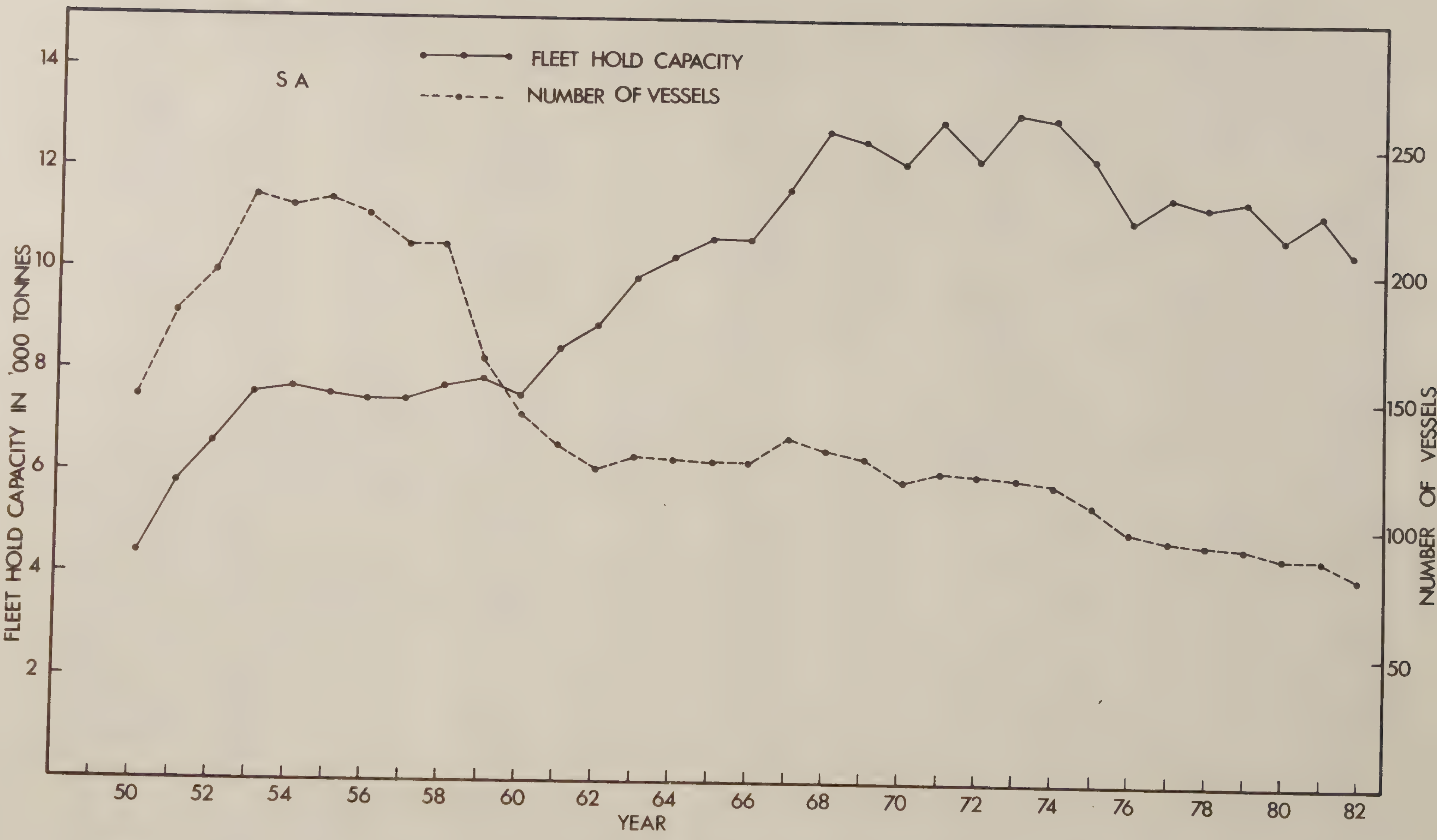

Fig. 3a. Trends in fleet hold capacity and number of vessels in the pelagic fisheries of SA.

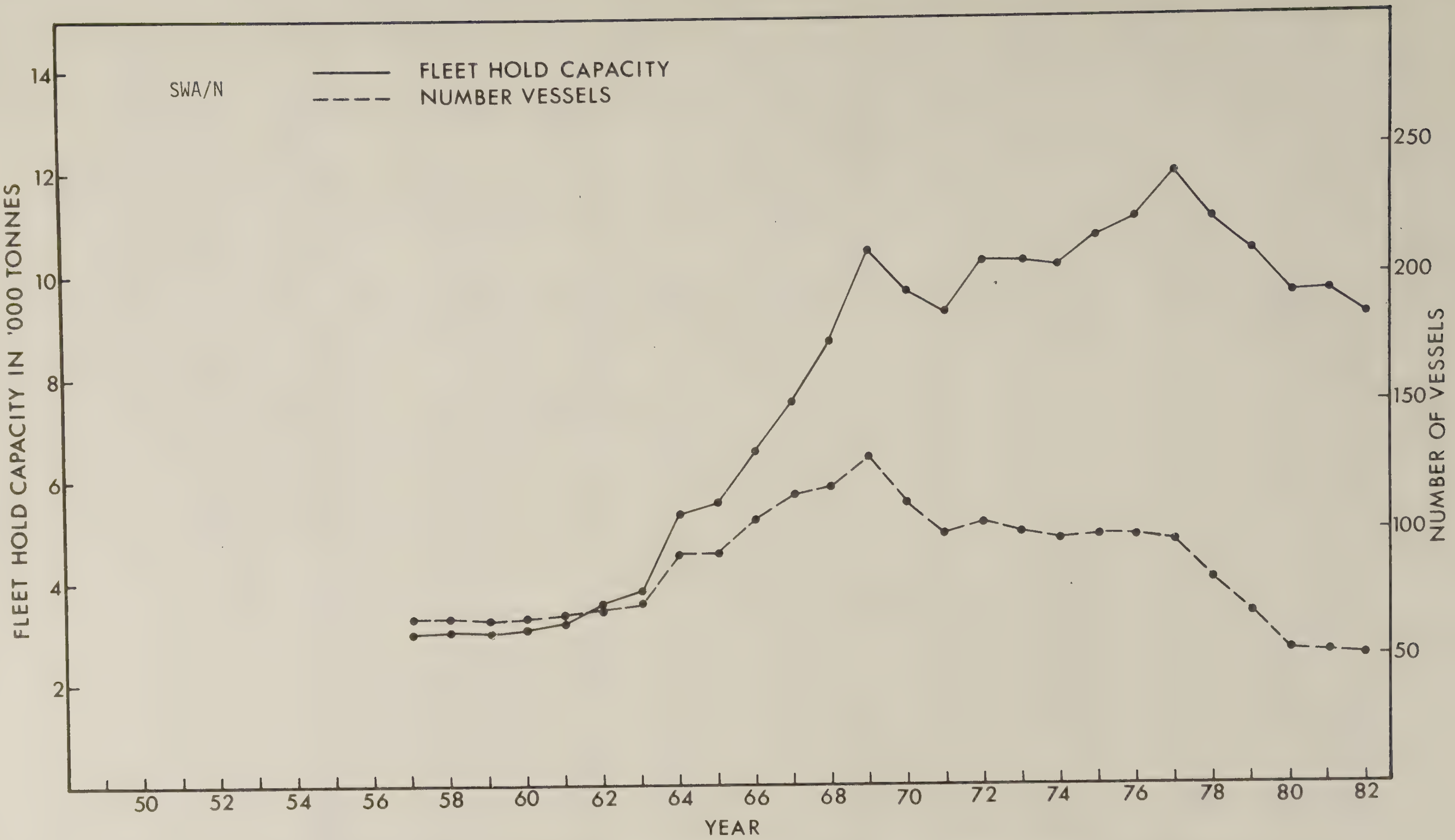

Fig. 3b. Trends in fleet hold capacity and number of vessels in the pelagic fisheries of SWA/N. (Data for SWA/N courtesy F. Schulein (pers. comm.)).

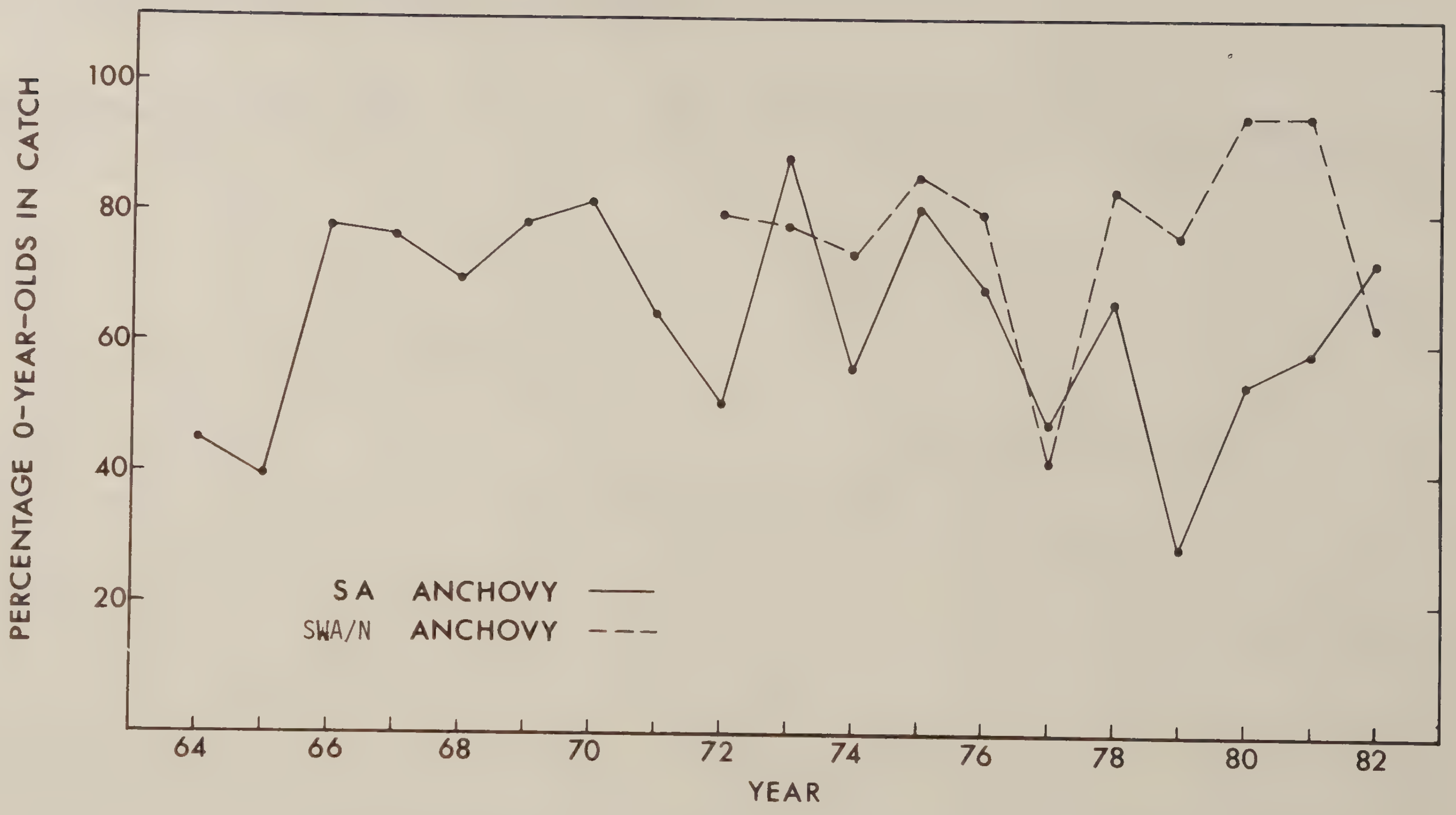

Fig. 4. Trends in the proportion by number of 0-year-olds in the anchovy landings in SA and SWA/N.

## Southwest African/Namibian Fishery

Like the SA pelagic fishery, the SWA/N fishery developed from shortly after the war. Fishing was carried out from the port of Walvis Bay (see Fig. 1) and for the first 20 years the industry was almost entirely based on a single species, the pilchard (Table 3, Fig. 5). Also indicated in these tables are foreign pilchard landings, primarily by Angola and the USSR; these are generally small, and only rarely have exceeded 20% of the SWA/N landings.

Closed seasons have applied for most of the history of the fishery (Table 4) for the same reasons as in SA: spawning season avoidance, low oil yield, and effort reduction. Spawning seasons are similar to SA, with a slightly later peak (le Clus and Thomas, 1982; le Clus and Melo, 1982).

Quotas were introduced in 1954. As in SA the basis for these was not scientific assessment of the stock, but essentially intuitive - in this case derived from the history of the Californian pilchard fishery. However, from 1959 quotas began to increase sharply coinciding with the rise in pilchard catches in SA, but were partially stabilized from 1964-1966 as the SA catch declined.

In 1966 a South African floating factory began operation off SWA/N, and a second the following year. This led in turn to further pressure for increased quotas for the land based industry and "set in motion an unhealthy trend in the fishery" (Anon. 1971).

Following an environmental anomaly in 1963 (Stander and de Decker, 1969), which led to a southerly displacement of pilchard shoals, a processing plant was opened in Lüderitz in 1964, and fishing continued from that port until 1974.

In 1963 experimental fishing for anchovy commenced with small mesh nets (11 mm). Good results obtained by vessels using these nets, plus three vessels capsizing through gilling of intermediate sized pilchards in the larger mesh (32 mm) nets, led to pressures which saw the smaller mesh nets universally used from August 1968.

After record pilchard landings in 1968, the industry was unable to fill quotas in 1969, and the factory vessels were requested to withdraw in 1970, although one returned in 1971.

The rapidly declining pilchard catch saw major management initiatives introduced in 1971. The global quota was split with a certain proportion for pilchard and the balance for other species.

The "other species" quota was never any effective restriction, not once being closely approached by catches from 1971 to 1977. Indeed its intention was rather to encourage diversification of the excess fishing effort available away from pilchard; also in the light of the possibility that the pilchard stock might be suffering from competition from the anchovy, it was at that time regarded desirable to subject the anchovy to heavy fishing pressure.

In 1971 a major research programme, the Cape Cross Programme, commenced. Heavy accent was placed on surveys, both egg-larvae and aerial-acoustic. Though these did not permit sustainable yield evaluation, they did provide a relative (if not absolute) index of pilchard biomass trend; scientific advice with regard to increasing the pilchard proportion of the global quota was empirically based primarily on the results of aerial surveys.

Cram (1981) documents the reasons underlying suspension of the surveys in 1975 and 1976. Essentially there were administrative delays in transferring the research staff base from Walvis Bay, where it had proved impossible to retain the staff required for the surveys, to Cape Town. The belief that the crisis of the collapse of the late 1960's was past and the stock could "now be considered as recovered" (Cram, 1977), probably also contributed to diminished concern.

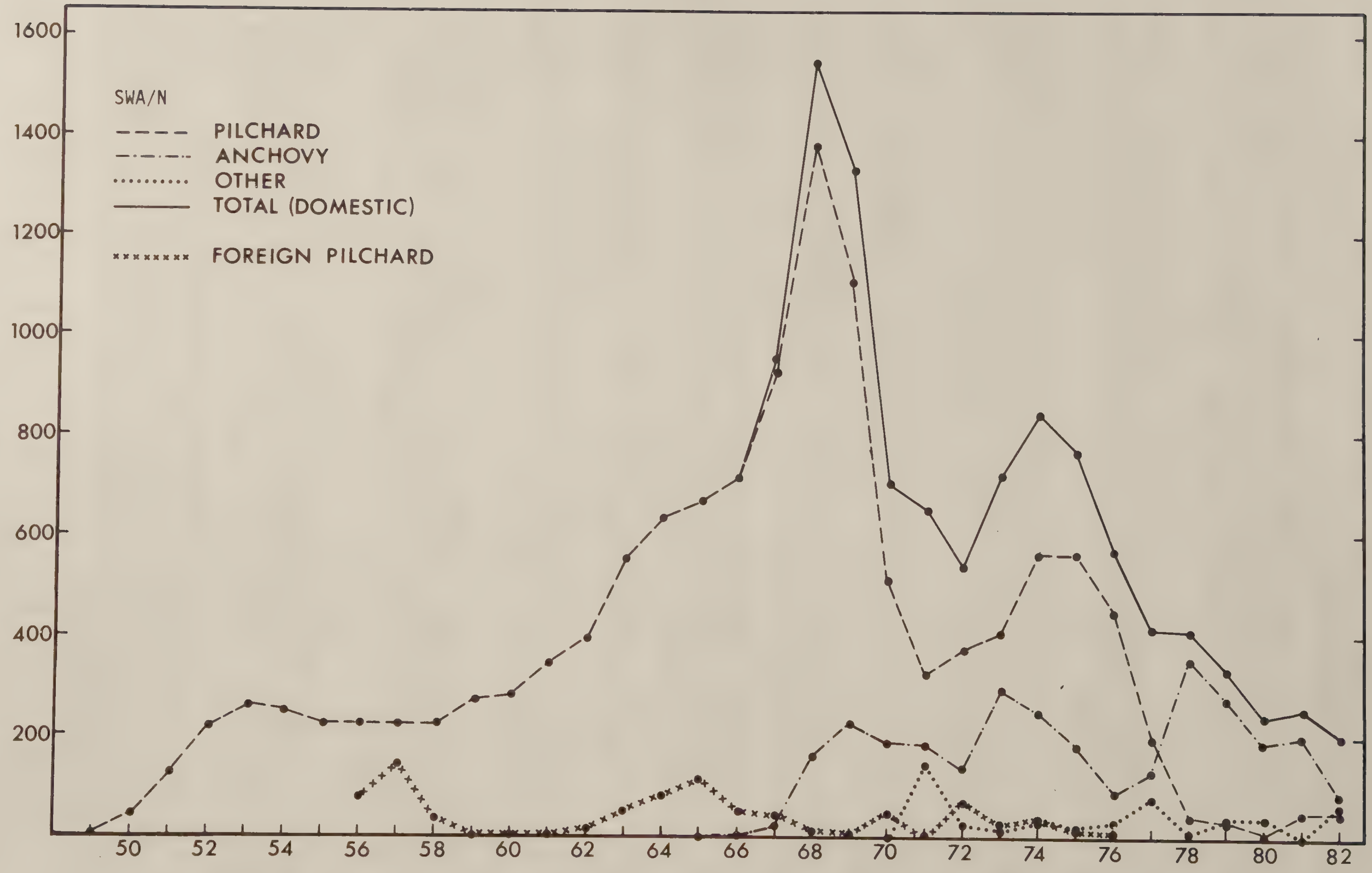

Fig. 5. Total domestic annual landings, and landings per species in the SWA/N pelagic fishery 1949-1982. The foreign (predominantly Angola and USSR) pilchard catch is also shown.

Table 3: Species composition of Southwest African/Namibian purse seine landings ('000 tonnes) 1947-1982

| Year | Local Industry | | | | | Foreign Catch (Pilchard) |
|---|---|---|---|---|---|---|
| | Pilchard | Anchovy | Horse Mackerel | Other | Total | |
| 1947 | 1 | - | - | - | 1 | - |
| 1948 | 3 | - | - | - | 3 | - |
| 1949 | 8 | - | - | - | 8 | - |
| 1950 | 47 | - | - | - | 47 | - |
| 1951 | 127 | - | - | - | 127 | - |
| 1952 | 226 | - | - | - | 226 | - |
| 1953 | 262 | - | - | - | 262 | - |
| 1954 | 251 | - | - | - | 251 | - |
| 1955 | 227 | - | - | - | 227 | - |
| 1956 | 228 | - | - | - | 228 | 80 |
| 1957 | 228 | - | - | - | 228 | 147 |
| 1958 | 229 | - | - | - | 229 | 40 |
| 1959 | 274 | - | - | - | 274 | 5 |
| 1960 | 283 | - | - | - | 283 | 10 |
| 1961 | 344 | - | - | - | 344 | 7 |
| 1962 | 397 | - | - | - | 397 | 14 |
| 1963 | 555 | - | - | - | 555 | 53 |
| 1964 | 636 | 1 | - | - | 637 | 82 |
| 1965 | 666 | 1 | - | - | 667 | 114 |
| 1966 | 719 | 3 | - | - | 722 | 57 |
| 1967 | 926 | 24 | - | - | 950 | 44 |
| 1968 | 1.387 | 161 | - | - | 1,548 | 14 |
| 1969 | 1,110 | 226 | - | - | 1,336 | 10 |
| 1970 | 514 | 189 | - | - | 703 | 51 |
| 1971 | 325 | 185 | 140 | 5 | 655 | 3 |
| 1972 | 374 | 137 | 22 | 2 | 535 | 73 |
| 1973 | 408 | 296 | 12 | 4 | 720 | 24 |
| 1974 | 562 | 249 | 30 | 2 | 843 | 35 |
| 1975 | 561 | 186 | 14 | 8 | 769 | 15 |
| 1976 | 452 | 88 | 23 | 8 | 571 | 11 |
| 1977 | 200 | 133 | 82 | 1 | 416 | ? |
| 1978 | 46 | 355 | 10 | 0 | 411 | 5 |
| 1979 | 34 | 277 | 28 | 2 | 341 | 6 |
| 1980 | 11 | 190 | 39 | 0 | 240 | 1 |
| 1981 | 52 | 199 | 4 | 0 | 255 | ? |
| 1982 | 51 | 84 | 67 | 0 | 202 | ? |

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NOTES FOR TABLE 4:

i) Figures shown for 1966-67 for factory ships represent estimated catches; as no quotas were applied.

ii) Minor extensions to the season for experimental purposes in 1972-74 have not been shown.

iii) For 1978, the closure data shown corresponded to filling of the quota.

iv) For 1979-80, the pilchard quota applied to the quantity of pilchard canned only.

v) In years where measures were changed during the season, those shown are as finally applicable. Since 1979 measures have been very changeable and complex, and the tabular entries are intended to serve only as a representative summary.

Data 1947-1976 courtesy F. Schulein (pers. comm.).

Table 4: Management restrictions for SWA/N purse seine fishery 1947-1982

| Year | Season | Minimum net mesh size (mm) | Area Closure | Quotas ('000 tonnes) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pilchard | | Other | Anchovy | Global (All Species) |
| | | | | Shore | Factory Ship | | | |
| 1947-50 | ? | - | - | - | - | - | - | - |
| 1951 | 1/1-31/3<br>1/5-31/12 | 38 | | - | | | | |
| 1952 | 1/1-29/2<br>1/5-31/12 | 38 | | - | | | | |
| 1953 | 1/1-30/11 | 38 | | - | | | | |
| 1954 | 1/3-30/11 | 38 | | 251 | | | | |
| 1955 | 1/3-30/11 | 38 | | 227 | | | | |
| 1956 | 1/2-31/10 | 35 | | 227 | | | | |
| 1957 | 1/3-30/11 | 35 | | 227 | | | | |
| 1958 | 1/3-31/10 | 35 | | 227 | | | | |
| 1959 | 1/2-31/10 | 35 | | 272 | | | | |
| 1960 | 1/2-31/10 | 35 | | 281 | | | | |
| 1961 | 1/4-31/12 | 35 | | 340 | | | | |
| 1962 | 1/3-30/11 | 35 | | 395 | | | | |
| 1963 | 1/3-31/12 | 35; 11 (2 vessels) | | 544 | | | | |
| 1964 | 1/3-30/11 | 35; 11 (16 vessels) | | 653 | | | | |
| 1965 | 1/1-31/10 | 35: 11 (16 vessels) | | 667 | | | | |
| 1966 | 1/2-31/12 | 35; 11 (16 vessels) | | 667 | (45) | | | |
| 1967 | 1/1-31/12 | 35; 11 (16 vessels) | | 800 | (236) | | | |
| 1968 | 1/1-31/12 | 35; 11 (all vessels from Aug.) | | 880 | 452 | | | |
| 1969 | 1/2-31/12 | 11 | | 880 | 412 | | | |
| 1970 | 1/2-31/10 | 11 | | 1,333 | - | | | |
| 1971 | 1/2-31/8 | 11 | North lat. 20°30'S | 271 | 181 | | | |
| 1972 | 1/3-31/8 | 11 | North lat. 20°30'S | 370 | | 542 | | |
| 1973 | 1/3-31/8 | 11 | North lat. 20°30'S | 460 | | 446 | | |
| 1974 | 1/2-31/8 | 11 | North lat. 20°30'S | 575 | | 372 | | |
| 1975 | 1/3-31/8 | 11 | North lat. 20°30'S | 571 | | 372 | | |
| 1976 | 1/3-31/8 | 11 | North lat. 20°30'S | 475 | | 465 | | |
| 1977 | 14/3-31/8 | 11 | | 200 | | 741 | | |
| 1978 | 27/3-30/7 | 11 | | 125 | | | | 410 |
| 1979 | 20/3- 3/9 | 11 | | 12.5 (can) | | | | 341 |
| 1980 | 7/4-13/8 | 11 | Various | 4.0 (can) | | | 250 | |
| 1981 | 23/3-27/4<br>18/5-29/7 | 11 | Various | No canning | | | | 243 |
| 1982 | 20/3- 1/5<br>1/6- 9/9 | 28 (RSW only)<br>11 | | 30 (RSW) | | | 220 | |

NOTES FOR TABLE 4: Please refer to footnote beneath Table 3.

Over this period the pilchard quota was retained at its 1974 level on the basis of CPUE trends, until a fishermen's strike following their concern at the lack of availability of fish saw the quota reduced by some 20% during the 1976 season. The 1977 quota was cut substantially when a pre-season aerial survey failed to reveal any major pilchard concentrations.

In 1978 with the recollapse of the pilchard stock evident, it was realized that the policy regarding other species required revision, as the anchovy had become the mainstay of the fishery and should be protected by more realistic quotas.

Historic performance over periods where fishing effort on anchovy had been essentially unrestricted indicated an average yield of some 200 thousand tonnes. A Schaefer model MSY calculation using annual catches and biomasses estimated using VPA produced a similar figure, though with large associated variance (le Clus and Melo, 1981).

The proportion of 0-year-old anchovy in the landings is extremely high (Fig. 4). While catches containing a larger proportion of adult anchovy are made to the far north of Walvis Bay throughout the season, the fishery relies predominantly on the "anchovy run" with large landings of 0-year-olds captured between latitude 22-23$^{O}$S over the May-August period.

The initial 1978 anchovy quota of 200 thousand tonnes was increased during the season following indications from catch rates of good anchovy recruitment. Extensive egg surveys were reintroduced over the 1978-1979 spawning season, and subsequent scientific advice has been along the lines of an initial annual quota of some 150 thousand tonnes, to be revised during the season in the light of results of the egg survey and indications of recruitment strength from catch rates.

Actual management decisions have fluctuated somewhat over this period: a global quota in 1979, a form of the scientific proposals for the next two years, then a fixed anchovy quota of 220 thousand tonnes for 1982, when only 84 thousand tonnes were landed despite a two week entension of the fishing season following delayed and poor recruitment.

For the pilchard, scientific advice since 1978 has been based on forward projections of VPA stock estimates assuming recruitment proportional to spawning biomass, where the constant of proportionality is taken as the average of that figure for the preceding few years.

Because of economic returns and labour considerations pressure for a pilchard quota to allow some canning of pilchard (the most profitable feature of the industry) to continue has remained, though no canning occurred in the 1981 season following the poor 1980 catch.

Until 1977, pilchard catches were mainly in the region latitude 20-23$^{O}$S, but subsequently have been much further north 18-20$^{O}$S. Pilchard catching in this area has usually been restricted to vessels with RWS (refrigerated sea water) facilities, so that the catch remains fit for canning during the 20-35 hour return trip to Walvis Bay.

A further problem has been the by-catch of pilchards with anchovy shoals early in the season. Catch composition has been monitored on a daily basis, and areas where pilchard by-catch is high closed to fishing. This method has also been used to prevent capture of very small anchovy ($\lesssim$ 8 cm) as yield per recruit calculations indicate it preferable that netting of such fish be delayed.

In 1982 the early part of the season was restricted to RSW vessels operating with 28 mm mesh (too large to catch anchovy). The 11 mm mesh was permitted only from June when indications are that the juvenile pilchard have outgrown and separated from anchovy shoals, so that pilchard by-catch is reduced.

The historical trends indicated for this fishery are quite probably confounded to some extent by alleged illegal practices, which Cram (1981) documents in some detail. Such practices may have taken three forms:

a) Underrecording of landings: it is rumoured, for example, that the officially recorded pilchard catch maximum of 1400 thousand tonnes achieved in 1968, was in fact in excess of 2 million tonnes.

b) Species misidentification: the split quota system introduced in 1971 imposed initially substantial restrictions on pilchard landings, and misidentification of pilchard as other species has been alleged. Though species identification of the catch was not carried out accurately prior to 1971, it remains suggestive that in that year of the most strenuous pilchard restrictions, 140 thousand tonnes of horse mackerel is recorded landed, a figure never since approached by the pelagic fleet.

c) Dumping: species identification is problematic prior to catching, and in situations where pilchard quotas have been the limiting considerations, and also with factories wanting to can as much of the pilchard quota as possible, so requiring only pilchard in appropriately good condition, rumours of dumping have persisted up to the present day.

To eliminate the incentive to dump pilchard, the pilchard proportion of the global quota in 1979 was amended to a maximum allowance of pilchard for canning. However, this left the problem of unacceptably high pilchard by-catches, and was superceded by the further area, mesh size, and season restrictions described above.

## STOCK ASSESSMENT TECHNIQUES

### Virtual population analysis

VPA has been the principle method recently used to provide a baseline for comparison of abundance indices over the history of the fisheries, together with information on recruitment fluctuations, stock projections, and MSY estimates.

Biomass calculations from VPA for the four stocks under consideration are shown in Fig. 6. These VPA calculations of fishing mortality assume a fishing season from January to August in SA and from March to August in SWA/N, with 0-year-olds available only from May. These values of fishing mortality, together with von Bertalanffy type age-weight relations have been used to estimate biomass on a monthly basis. Recruitment is assumed to occur linearly over the March-June period for a more realistically smooth plot than would be produced by knife-edged recruitment.

Fig. 7 shows plots of recruitment against spawning biomass. Anchovy can reach full maturity in one year, and pilchard in two (though Thomas, pers. comm., reports indications of SWA/N pilchard now mature after a single year). Spawning biomass is thus taken as that present on the 1st January (approximate mid-point of spawning season) of that year, except that the youngest age class is excluded for the SA pilchard.

Beverton-Holt and Ricker type fits to these plots have been calculated using non-linear regression (minimize $\Sigma(R-\hat{R})^2$) and are shown in Fig. 7. Shelton and Armstrong (1983) report evidence of change in the length (and hence presumably age) at maturity for both SA pilchard and anchovy over the history of the fisheries. Such behaviour, which is consistent with a density dependent response of the adult population to biomass changes, means that the spawning biomasses indicated in Fig. 7 are potential maxima, rather than values achieved, with the empirically fitted curves reflecting in part this response.

The VPA calculations are based on various imputs and algorithms which are discussed below:

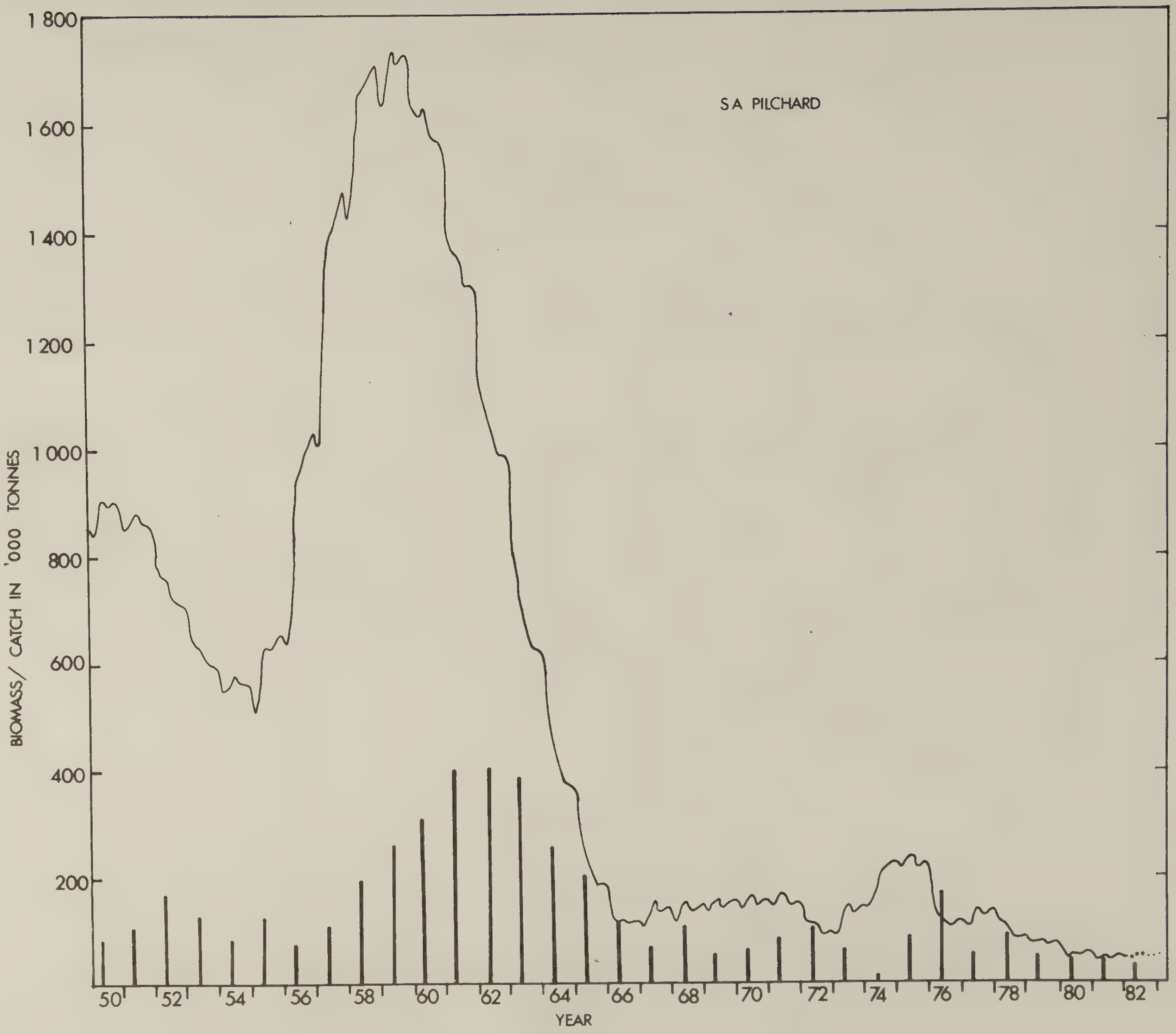
a) Annual catches

The possibility of underrecording, species misidentification, and dumping in SWA/N was discussed in the previous section, and may influence the biomass trends calculated. Foreign pilchard catches are included in the SWA/N calculations (including those by Angola - presumably from the same stock).

Fig. 6a.

Monthly trend in biomass calculated by VPA, and annual landings (represented by vertical bars) for SA pilchard.

Dashed portions (---) of the trends shown are less reliable.



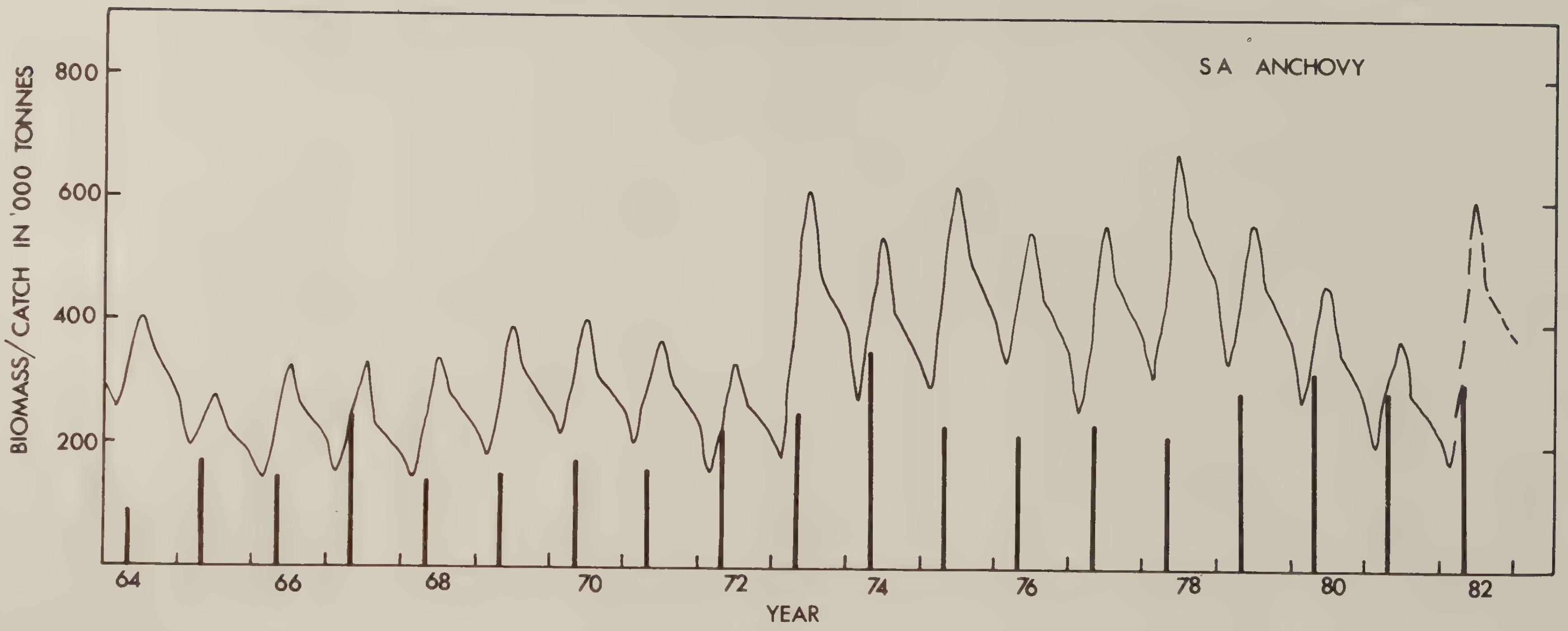


Fig. 6b. Monthly trend in biomass calculated by VPA, and annual landings (represented by vertical bars) for SA anchovy.
Dashed portions (---) of the trends shown are less reliable.

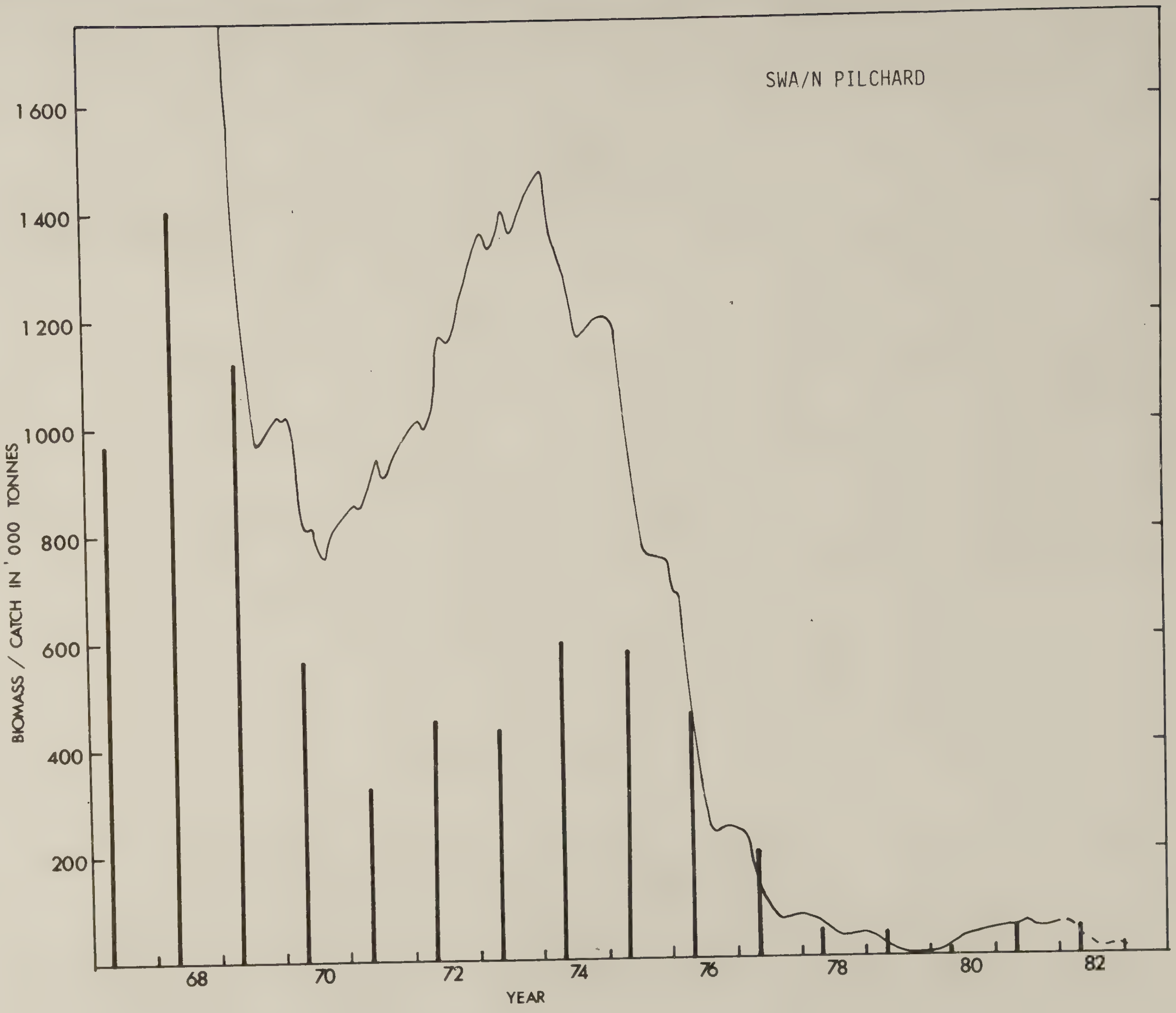


Fig. 6c.

Monthly trend in biomass calculated by VPA, and annual landings (represented by vertical bars) for SWA/N pilchard.

Dashed portions (---) of the trends shown are less reliable.

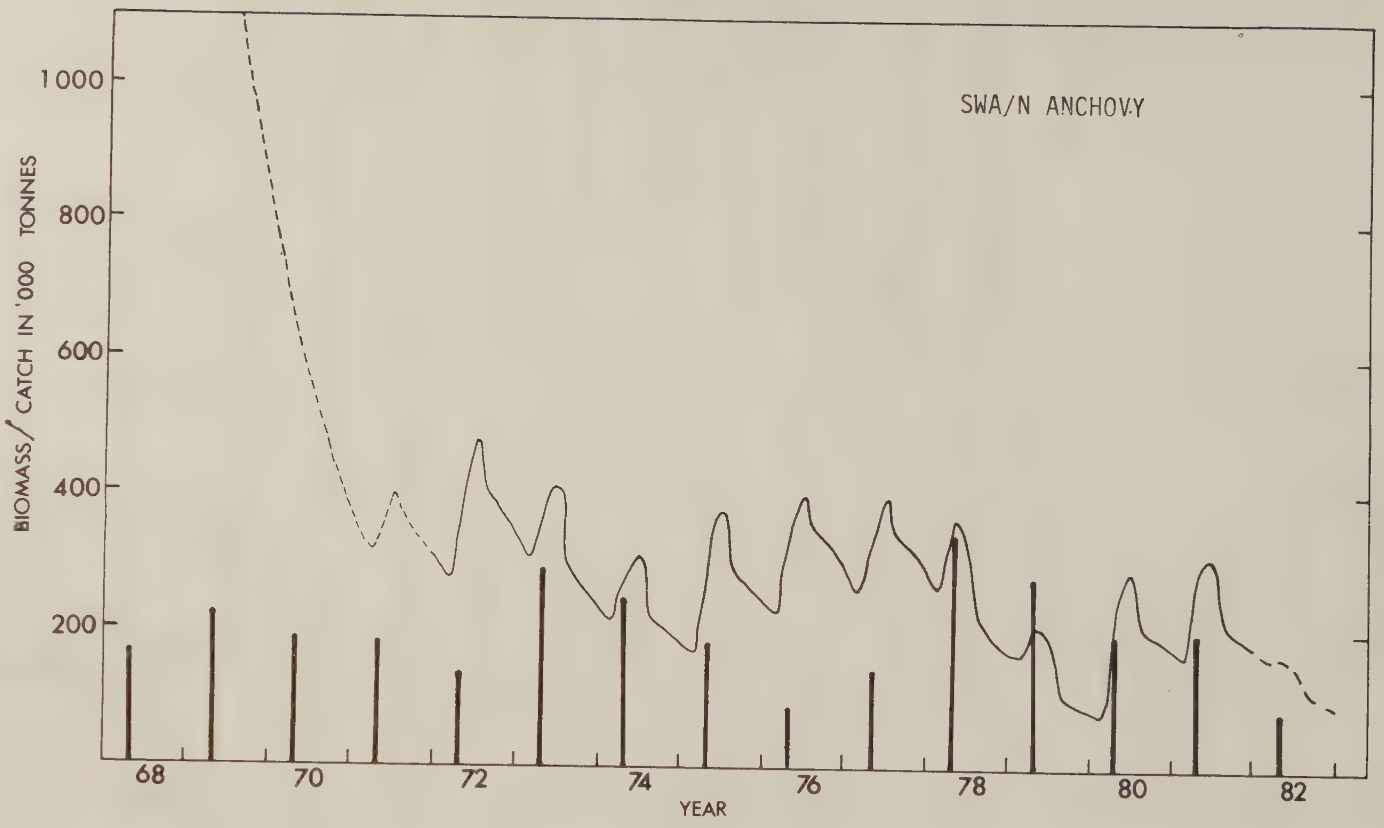


Fig. 6d. Monthly trend in biomass calculated by VPA, and annual landings (represented by vertical bars) for SWA/N anchovy.
Dashed portions (---) of the trends shown are less reliable.

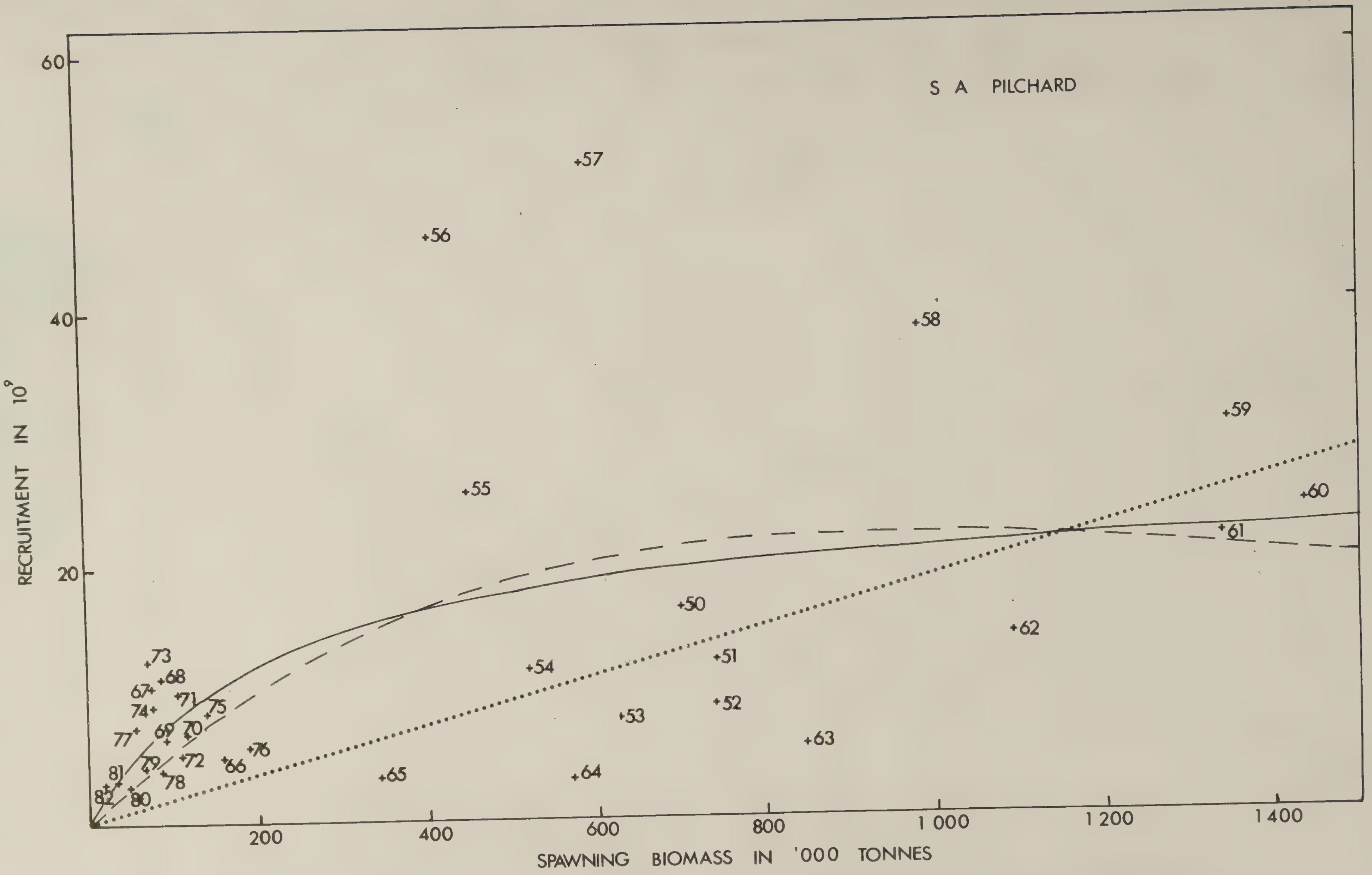


Fig. 7a. Plots of spawning biomass vs recruitment (0-group year-class strength) calculated by VPA for SA pilchard. Best fit Beverton-Holt and Ricker curves are indicated by (——) and (- - -) respectively. The dotted line is the replacement line corresponding to unexploited equilibrium states.

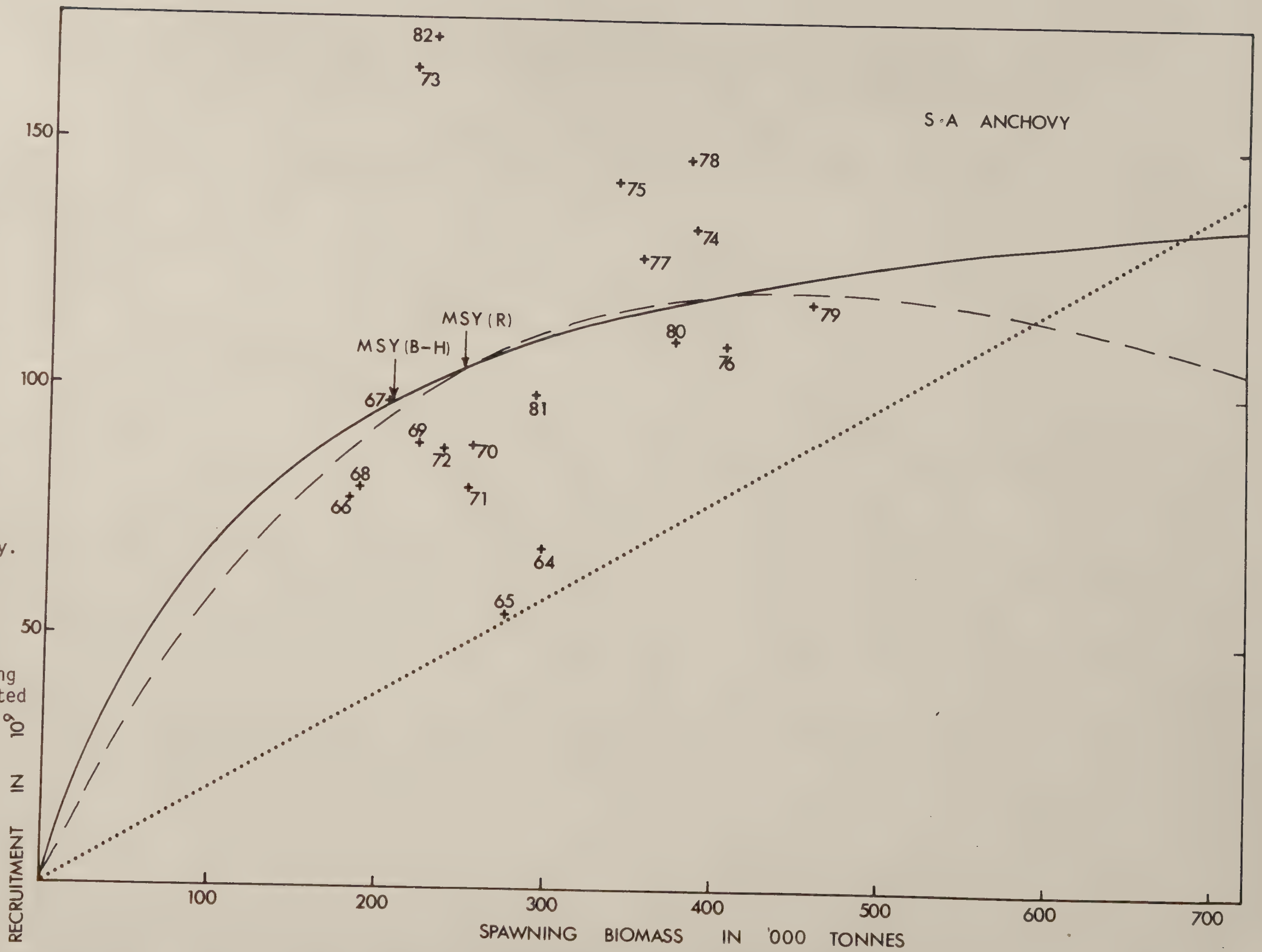


Fig. 7b. Plots of spawning biomass vs recruitment (0-group year-class strength) calculated by VPA for SA anchovy. Best fit Beverton-Holt and Ricker curves are indicated by (——) and (- - -) respectively. The dotted line is the replacement line corresponding to unexploited equilibrium states.

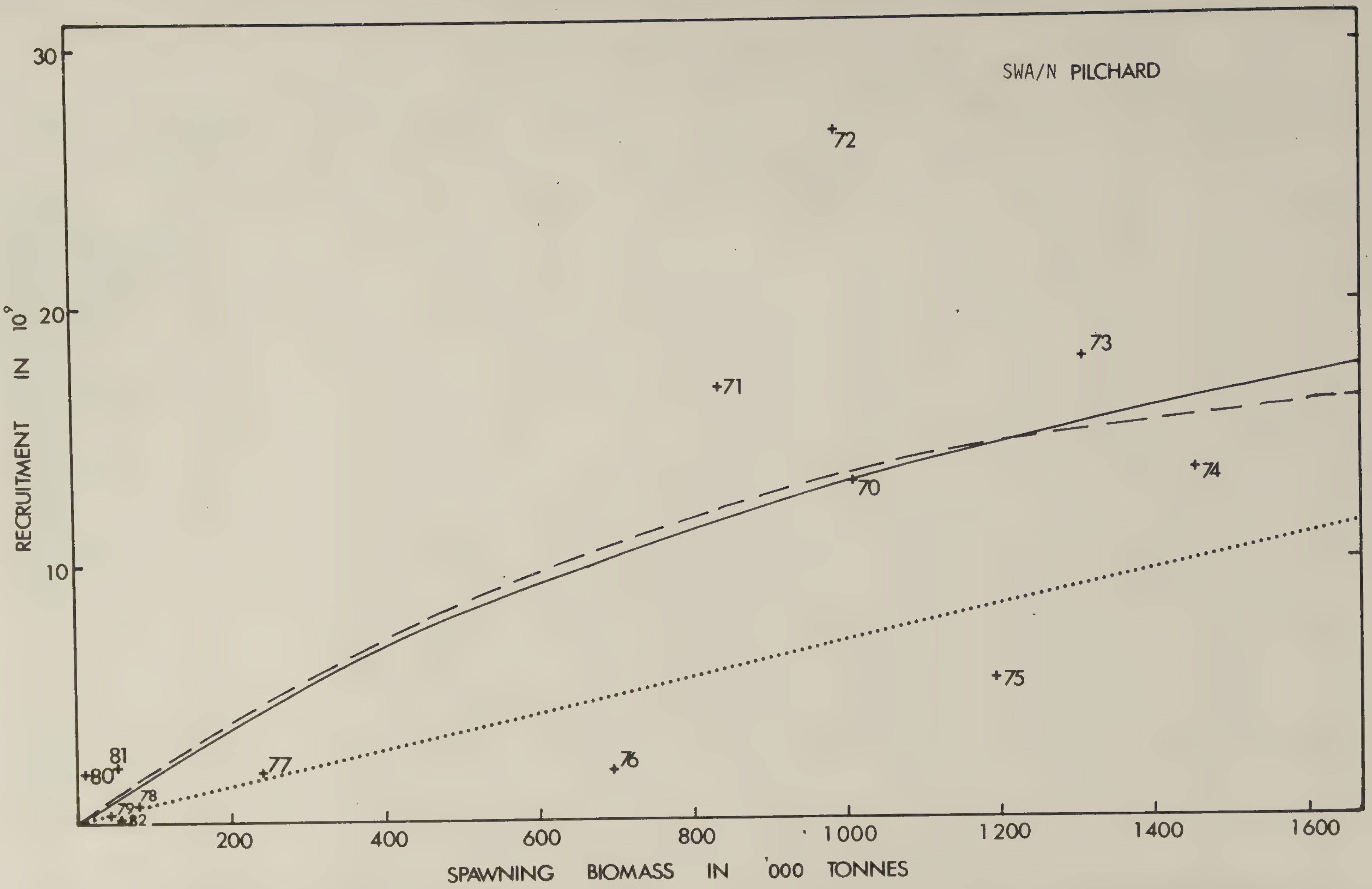
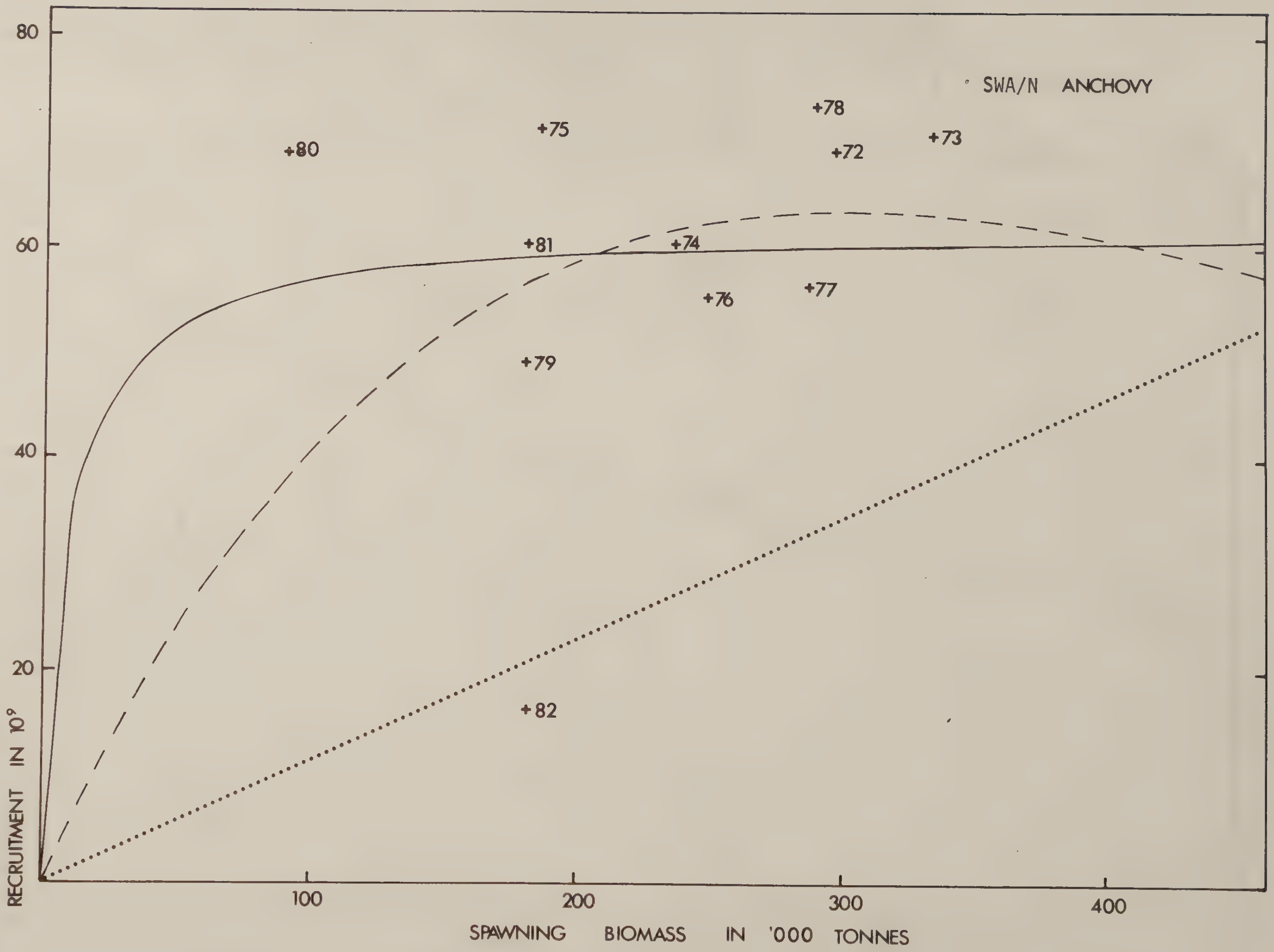


Fig. 7c. Plots of spawning biomass vs recruitment (0-group year-class strength) calculated by VPA for SWA/N pilchard. Best fit Beverton-Holt and Ricker curves are indicated by (——) and (- - -) respectively. The dotted line is the replacement line corresponding to unexploited equilibrium states.

Fig. 7d. Plots of spawning biomass vs recruitment (0-group year-class strength) calculated by VPA for SWA/N anchovy. Best fit Beverton-Holt and Ricker curves are indicated by (——) and (- - -) respectively. The dotted line is the replacement line corresponding to unexploited equilibrium states.



b) Age composition

Table 5 lists the methods used to derive age compositions from length compositions of the annual catches. The associated mean age trends of the catches are shown in Fig. 8.

A concern here is the frequency with which it has been necessary to apply age-length keys for data from one period to length composition data from another. Biomass calculations by VPA over a period where the age composition shows little trend can do no more than duplicate (slightly preceding) the catch history.

Fig. 9 and Table 6 show evidence of growth rate increase in the SWA/N pilchard corresponding to biomass reduction from the 1960's to 1970's. Modal length progression during the 1960's (Schulein and Thomas, pers. comm.) also suggest such increase, though these may also reflect the 1963 environmental anomaly (Stander and de Decker, 1969 ). Changes in the length at maturity for SA pilchard and anchovy referred to above, may also reflect compensatory growth rate changes. le Clus and Melo (1983) refer to possible changes in growth rate with area for the SWA/N anchovy.

Table 6: Annual growth increments in centimeters of SWA/N Pilchard from mean lengths of various ages in the catch each year.

| Age increment in Years | 1-2 | 2-3 | 3-4 | 4-5 |
|---|---|---|---|---|
| Period | | | | |
| 1967-68 | 1.2 | 0.4 | 0.2 | 0.4 |
| 1968-69 | | | | |
| 1969-70 | | | | |
| 1970-71 | | | | |
| 1971-72 | 2.6 | 1.3 | 0.8 | 0.6 |
| 1972-73 | 2.4 | 1.1 | 0.7 | 0.6 |
| 1973-74 | 1.6 | 0.9 | 0.8 | 0.7 |
| 1974-75 | 1.1 | 0.8 | 0.7 | 0.5 |
| 1975-76 | 2.1 | 0.5 | 0.3 | -0.1 |
| 1976-77 | 2.1 | 0.7 | 0.1 | 0.0 |
| 1977-78 | 1.1 | 0.3 | -0.1 | -0.3 |
| 1978-79 | 2.1 | 1.3 | 1.1 | 1.0 |
| 1979-80 | 4.4 | 1.7 | 1.0 | 1.1 |
| 1980-81 | 3.9 | 1.9 | 1.7 | 1.2 |

The mean age time series shown in Fig. 8 show suspiciously little trend in some cases contrary to what might be expected with presumably large changes in fishing intensity. They could however be confounded by density dependent changes to age length keys, thus introducing bias to both biomass and recruitment estimates.

This underlines the importance of regular ageing analyses, and the possible unreliability of length distributions as an index of the health of pelagic fish stocks.

c) Natural mortality (M)

Calculations of natural mortality from the age distribution of initial catches is viable only for one of the stocks under consideration here. Length distribution data is not available for the earliest years of either pilchard fishery; and even for the first years for which it is, age length keys from other periods would have to be applied. Length data for the opening years of anchovy fishing in SWA/N is based on small and probably unrepresentative samples (hence also the unreliability of biomass estimates for that period: Fig. 6d).

For the first two years (1964-1965) of the SA anchovy fishery, by disregarding 0-year-olds as not fully selected, and 4-year-olds as unrepresentatively small in number one obtains estimates ranging from 0.82 to 1.36 with a mean of 1.14.

Table 5: Basis for establishing age-length keys to obtain annual age composition of SA and SWA/N pilchard and anchovy catches for use in VPA.

| SA PILCHARD | | SA ANCHOVY | | SWA/N PILCHARD | | SWA/N ANCHOVY | |
|---|---|---|---|---|---|---|---|
| Period | Method | Period | Method | Period | Method | Period | Method |
| 1950-71 | Same key each year from otoliths collected 1965-67 | 1964-82 | Same key each year from scales collected 1965-67 | 1967-68 | Different key each year from otoliths of that year* | 1968-78 | Same key each year being average of keys for 1979-82 |
| 1971-82 | Different key each year from otoliths of that year | | | 1969-70 | Key average of 1968 and 1971 keys | 1979-82 | Different keys for each month based on otoliths |
| | | | | 1971-82 | Different key each year from otoliths of that year | | |

* No length data is available for the fish from which the otoliths were taken; accordingly an otolith size vs fish length regression has been used to construct the age-length key.

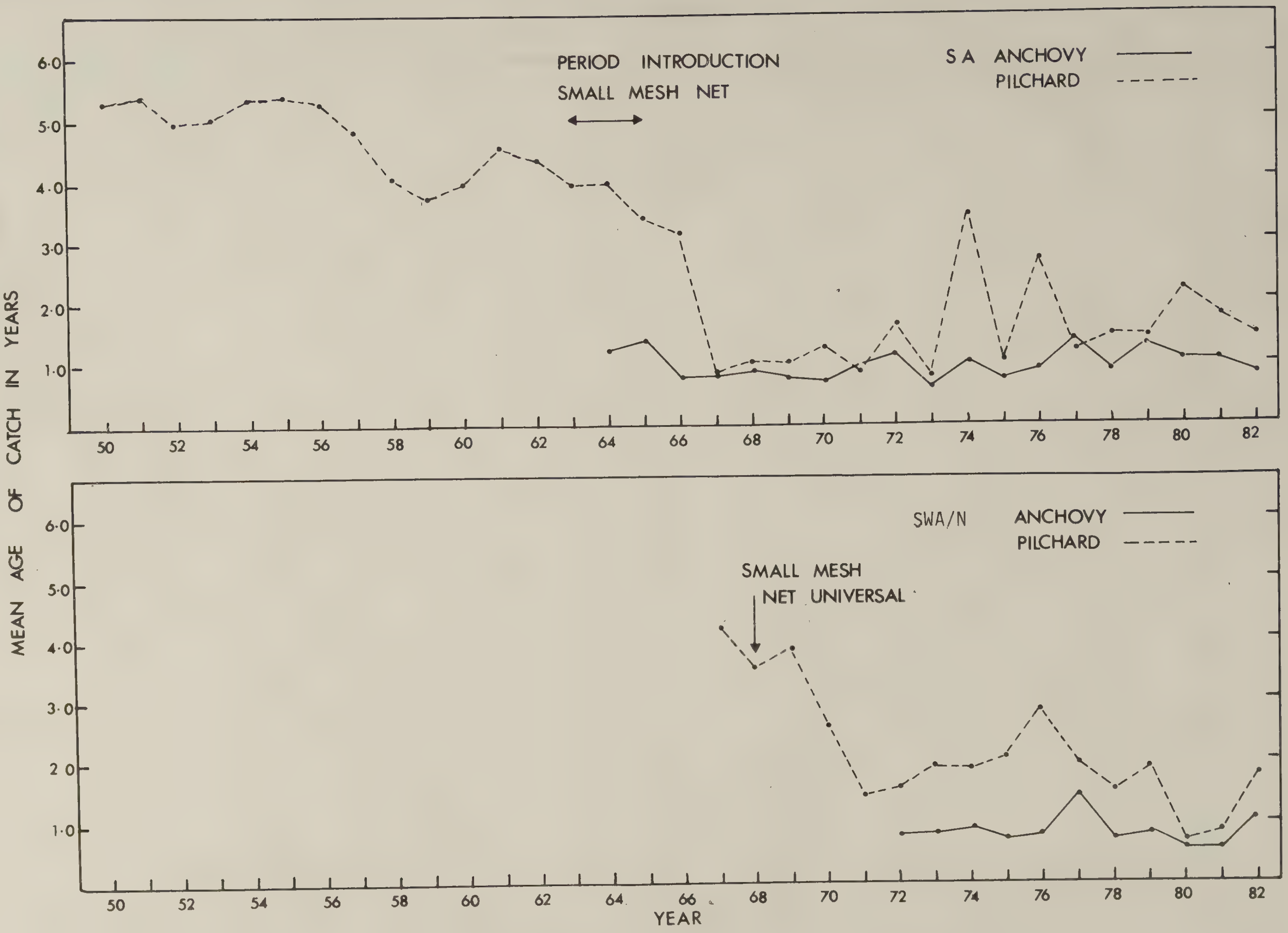


Fig. 8.
Mean age of
anchovy and
pilchard
in the
catches by
year.

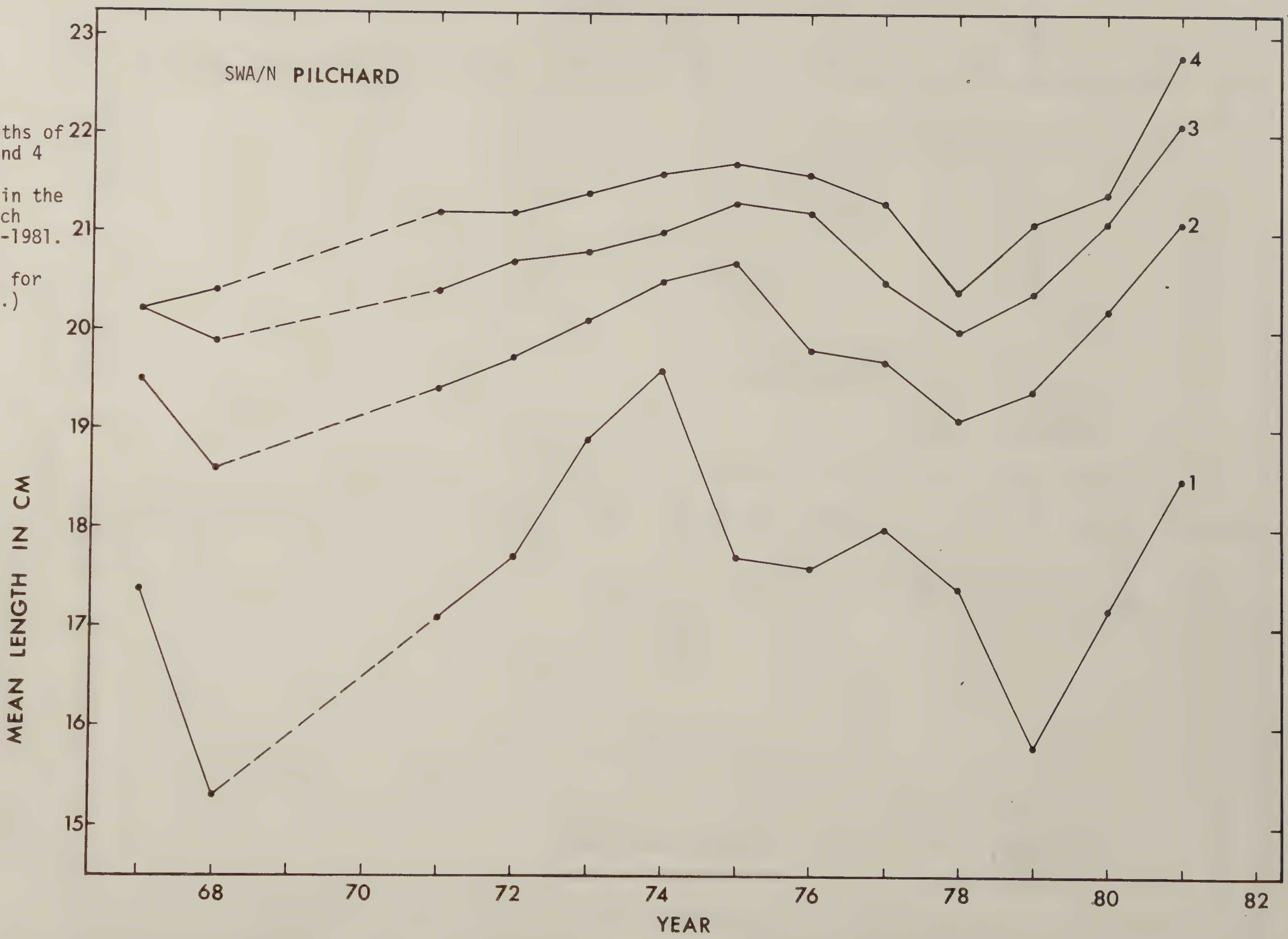


Fig. 9.
Mean lengths of 1, 2, 3 and 4 year-old pilchard in the SWA/N catch from 1967-1981. (Data not available for 1969-1970.)

Natural mortality is presumably a reflection in the main of predator consumption. The average of such consumption implied by VPA has been calculated over the period 1973-1982 for the SA anchovy and is shown in Fig. 10 for various values of M.

Also shown in Fig. 10 is an estimate (Eales, 1982), of annual anchovy consumption by seals, whales, and birds in the area. This is a lower limit in that the contributions of fish predators (such as snoek) and dolphins are omitted. Current research aims to improve these estimates.

An estimate of M=1.1 is reasonably consistent with both approaches and has been used for both anchovy stocks.

For pilchard a value of M=0.5 is traditional. Newman's (1970a) analysis of tag returns for SWA/N pilchard indicated total mortality Z in the 0.7-0.8 range for the period 1957-1966. This suggests that a value of M much higher than 0.5 is unlikely.

Trends in aerial estimates of the SWA/N pilchard stock are consistent with the value of M=0.5 (see subsequent section).

Using a fixed value for M is a simplification for an effect that must be dependent to some extent on the age of the fish, and response (conceivably delayed) of predator populations to changing prey biomass. While the biases that neglect of such effects may introduce into VPA estimates merit qualitative investigation, quantitative allowance seems at best a distant prospect.

d) Terminal Fishing Mortality ($F_t$)

VPA requires an estimate of the fishing mortality ($F_t$) of the oldest aged fish appearing in the catch from each year class. The prescription used here is to achieve iteratively a solution where the $F_t$ value for each year is an average of the F values for the other older ages that year, i.e. assuming that selectivities for the older ages would be the same.

$$F_t^y = \frac{1}{t-t'-1} \sum_{i=t'}^{t-1} F_i^y \qquad i=\text{age},\ y=\text{year}$$

Due to a greater age spread, the choice of $F_t$ makes little difference to estimates for pilchard, whereas for anchovy the sensitivity is quite substantial, and further work is needed to investigate whether such an algorithm introduces bias, and to try other methods such as that of Pope and Shepherd (1982).

For example, there is the possibility that the SA fishery does not exploit the full geographic range of the anchovy, and that the low proportion of adults in the catch is a reflection of emigration of the older fish from the fishing area rather than heavy exploitation. Anchovy are known to be present (and to spawn) well to the east of longitude 21°E, though the fraction of the total biomass this represents is unknown. A 1983 survey of pelagic-shoal-feeding Brydes whales off the SA west and south coasts has shown the major concentrations of these whales in this eastern region.

Such emigration could be represented by progressively lower selectivities for older anchovies. Fig. 11 compares the standard VPA series for the SA anchovy with that corresponding to $F_t$ decreased by 20% in the iterative algorithm. The difference is substantial emphasising the sensitivity to this aspect, and the need for simulation studies to test the extents to which invalid assumptions and algorithms may introduce trends that are artefacts rather than real effects.

e) Current Year Fishing Mortalities

Estimates of current ($\tilde{y}$) and immediately previous years' biomass - the main requirement for management - require values of F for each age of the most recent year. This has also been achieved iteratively from a value of the fishing effort for the year ($E^{\tilde{y}}$) and assuming F proportional to E, the constant of proportionality for each age being given by the average over the immediately previous few years:

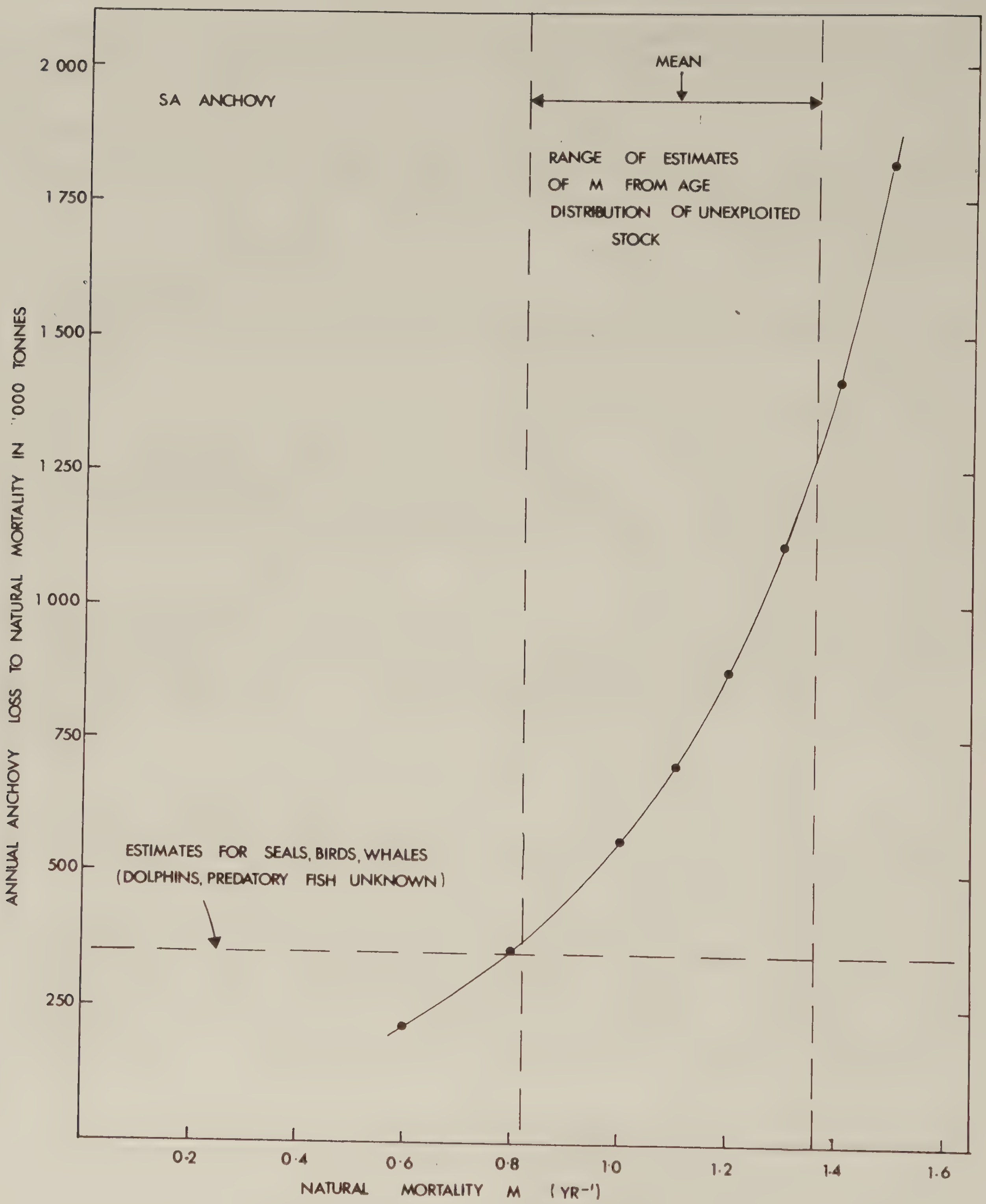


Fig. 10. Average annual loss of anchovy to natural mortality in SA over the period 1973-1982, estimated by VPA, as a function of anchovy natural mortality M.

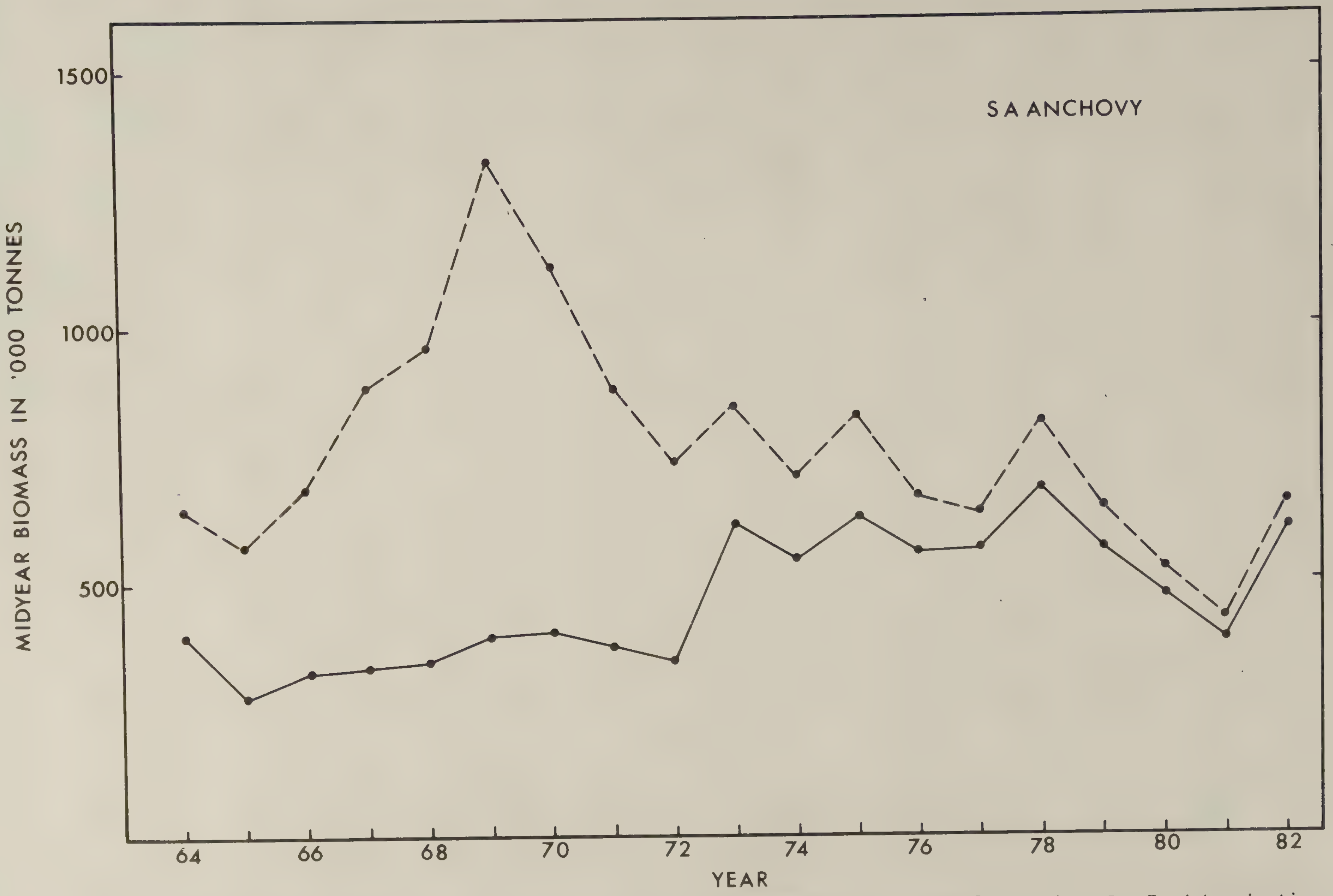


Fig. 11. Mid-season biomass trends for the SA anchovy from VPA corresponding to the normal procedure for $F_t$ determination (——), and a prescription lowering the selectivity of the oldest age-class by 20% (- - -) (see text).

$$F_i^{\tilde{y}} = E^{\tilde{y}} \frac{1}{\tilde{y}-y'-1} \overset{\tilde{y}-1}{\underset{y=y'}{\phantom{\sum}}} \frac{F_i^y}{E^y}$$

The appropriateness of the F proportional to E assumption is discussed in the following section.

CPUE

There are two problems with effort in a mixed-species purse-seine fishery: how to define it, and how to allocate it if species directed fishing is taking place.

Effort in the SA fishery has been calculated in "standard boat days" using a power factor analysis by multiple linear regression over the period 1964-1972 (Newman et al., 1979); a number of fishing aids (power-block, sonar, fish pump, smaller mesh nets) were introduced over this period, and their effect estimated in the analysis.

In SWA/N a product of vessel hold capacity (the most significant factor in the SA analysis) and time at sea has been used for the period since the inception of such data collection in 1972; the fishing aids listed above were all generally available over that period. Fuel issue has also been used as a measure of effort in SWA/N; data is available from 1965.

Theoretically the linear relation of CPUE to abundance relies on either uniform random distribution of fishing effort over the range of the fish stocks, or a uniform random distribution of fish (maintained by migration to compensate for localized catches). In the absence of species-directed fishing, the total effort applies to each species. In practice some species direction takes place through cooperation between vessels having identified a particular species in a certain area, so that a given species cannot be considered subject to the total effort applied. For SWA/N directed effort has been semi-arbitrarily defined as only those trips where the vessel's catch comprises more than 50% of the species under consideration and is counted towards the directed catch of that species. The total effort on the species is then this directed effort multiplied by the ratio of the catch to directed catch of the species. The results following use this species effort allocation for SWA/N but total effort for SA where data on effort allocation on this basis is not available.

Fig. 12 compares VPA mid-year biomasses and CPUE indices; the latter have been renormalized to the average VPA biomass over 1964-1982 (SA) and 1972-1982 (SWA/N). Plots of annual mean fishing mortalities ($\bar{F}$) against effort (E) are shown in Fig. 13; and of catchability $q=\bar{F}/E$ against biomass in Fig. 14. VPA estimates of fishing mortalities for each age weighted by the numbers caught of that age, have been used to calculate $\bar{F}$.

While broad trends in Fig. 12 are similar, there is much detailed difference. (For pilchard there is some indication that CPUE lags VPA, perhaps as the fishery exploits the older age-classes more heavily.) This is reflected in the large scatter in the $\bar{F}$ vs E plots in Fig. 13. Linear regressions have been shown in these as a guide to trends, and associated correlation coefficients are given in Table 7. In the case of the two SA fisheries it is clear that these trends are strongly influenced by outlying points in the plots. Only for the SWA/N anchovy does the trend approach the proportionality theoretically desirable.

The plots of catchability against biomass in Fig. 14 are to investigate the possibility that this increases with biomass decline, so that CPUE would underestimate a stock decrease; linear regressions are again shown to indicate trends. Little effect is apparent for the SA pilchard, but any trend may be confounded by failing to take SA species direction of effort into account. There are negative trends for both anchovy stocks, but these are again strongly influenced by outlying points.

For the SWA/N pilchard there is as marked increase of q as biomass declined; the associated CPUE underestimate of stock decrease is evident in Fig. 12c. For SWA/N lower CPUE values correspond to northward contraction of the stock as it declines so that vessels had to travel further from port to make catches. It is reasonable to assume that the

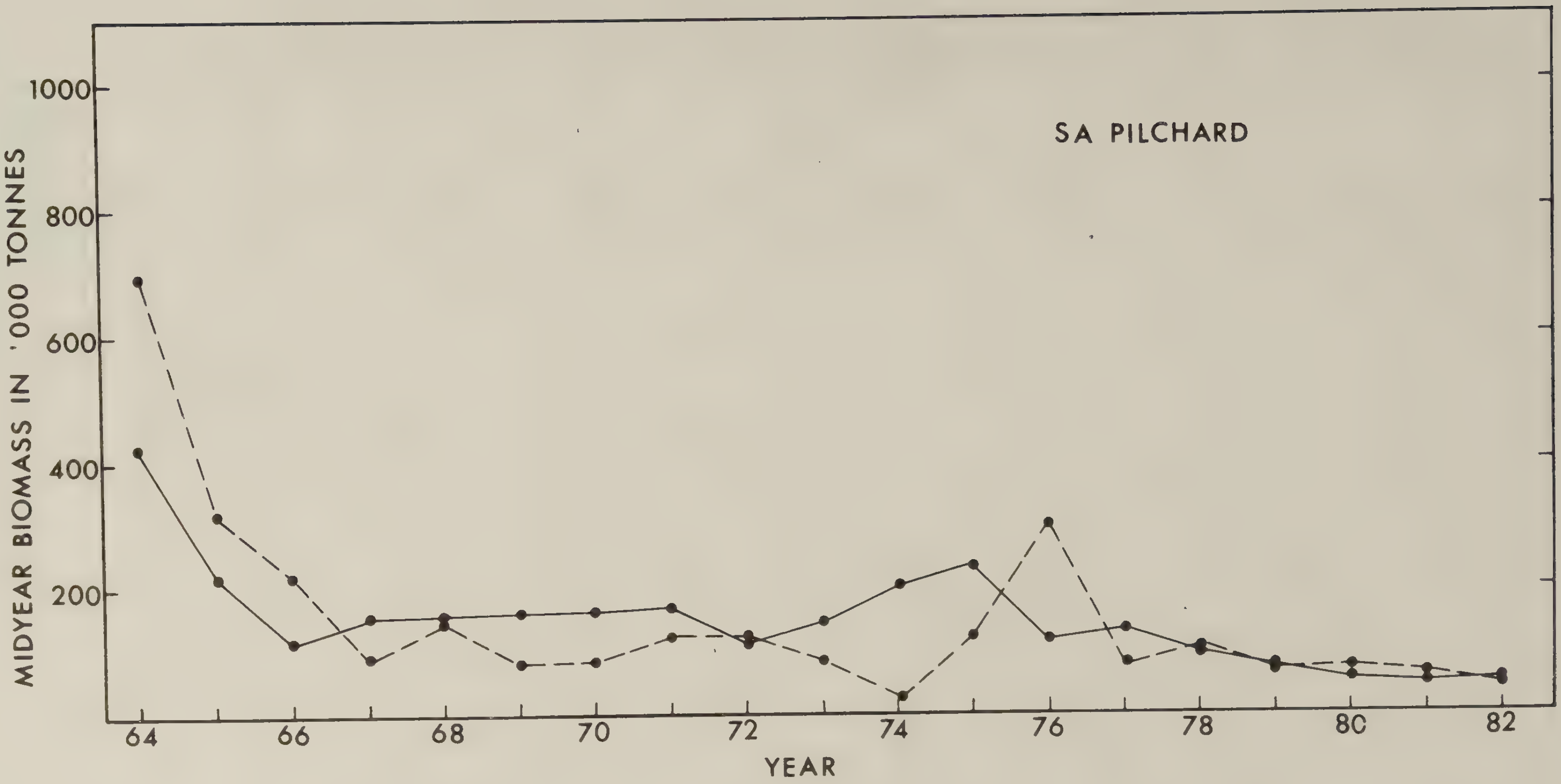


Fig. 12a. Comparison of VPA estimates of mid-year biomass (solid line) with CPUE indices for SA pilchard. The CPUE indices have been renormalised to the average of the VPA biomasses over the periods 1964-1982 for SA and 1972-1982 for SWA/N. For SA the effort measure used is "standard boat days" (undirected), and the index is indicated by (- - -).

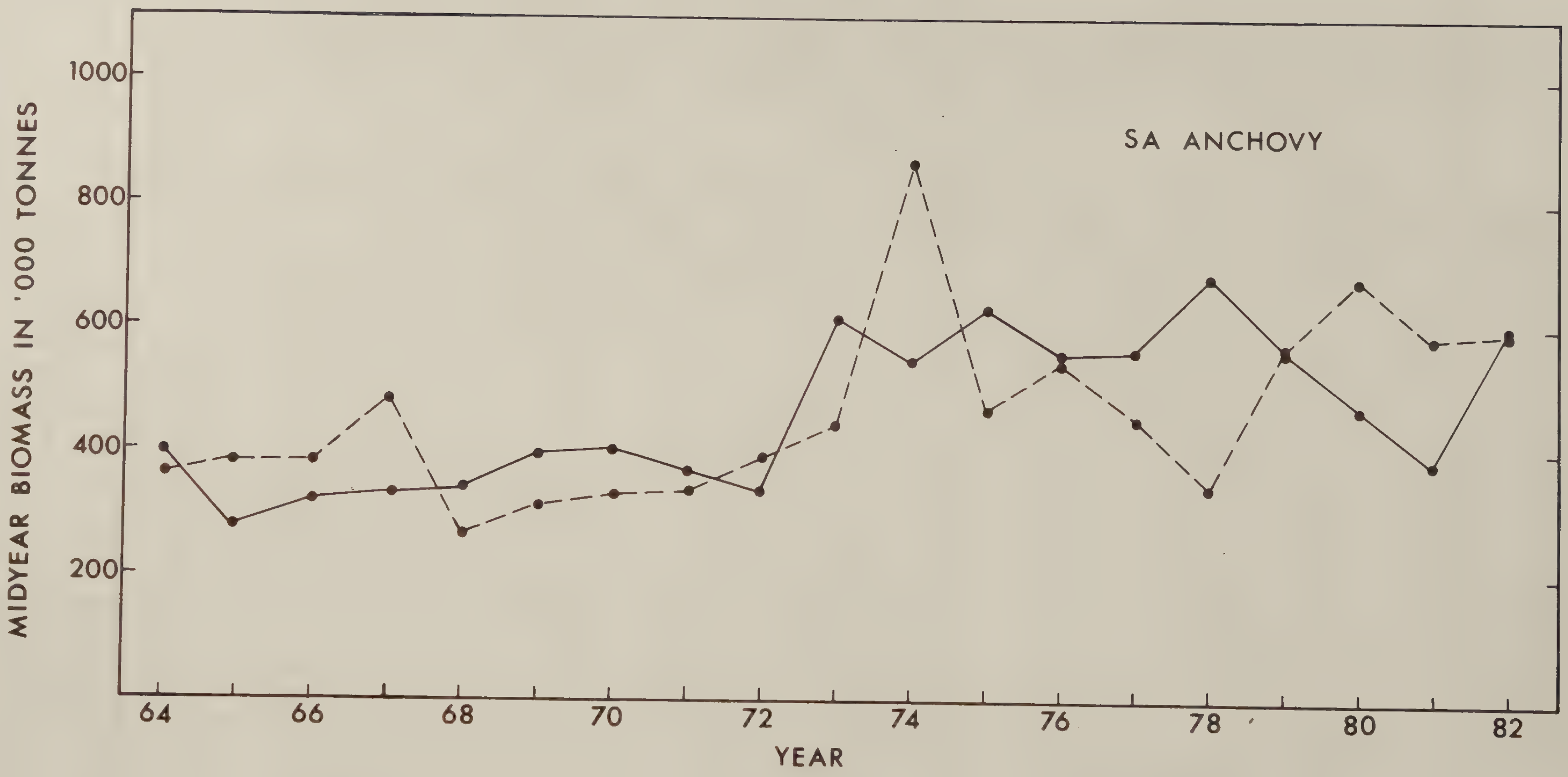


Fig. 12b. Comparison of VPA estimates of mid-year biomass (solid line) with CPUE indices for SA anchovy. The CPUE indices have been renormalised to the average of the VPA biomasses over the periods 1964-1982 for SA and 1972-1982 for SWA/N. For SA the effort measure used is "standard boat days" (undirected), and the index is indicated by (- - -).

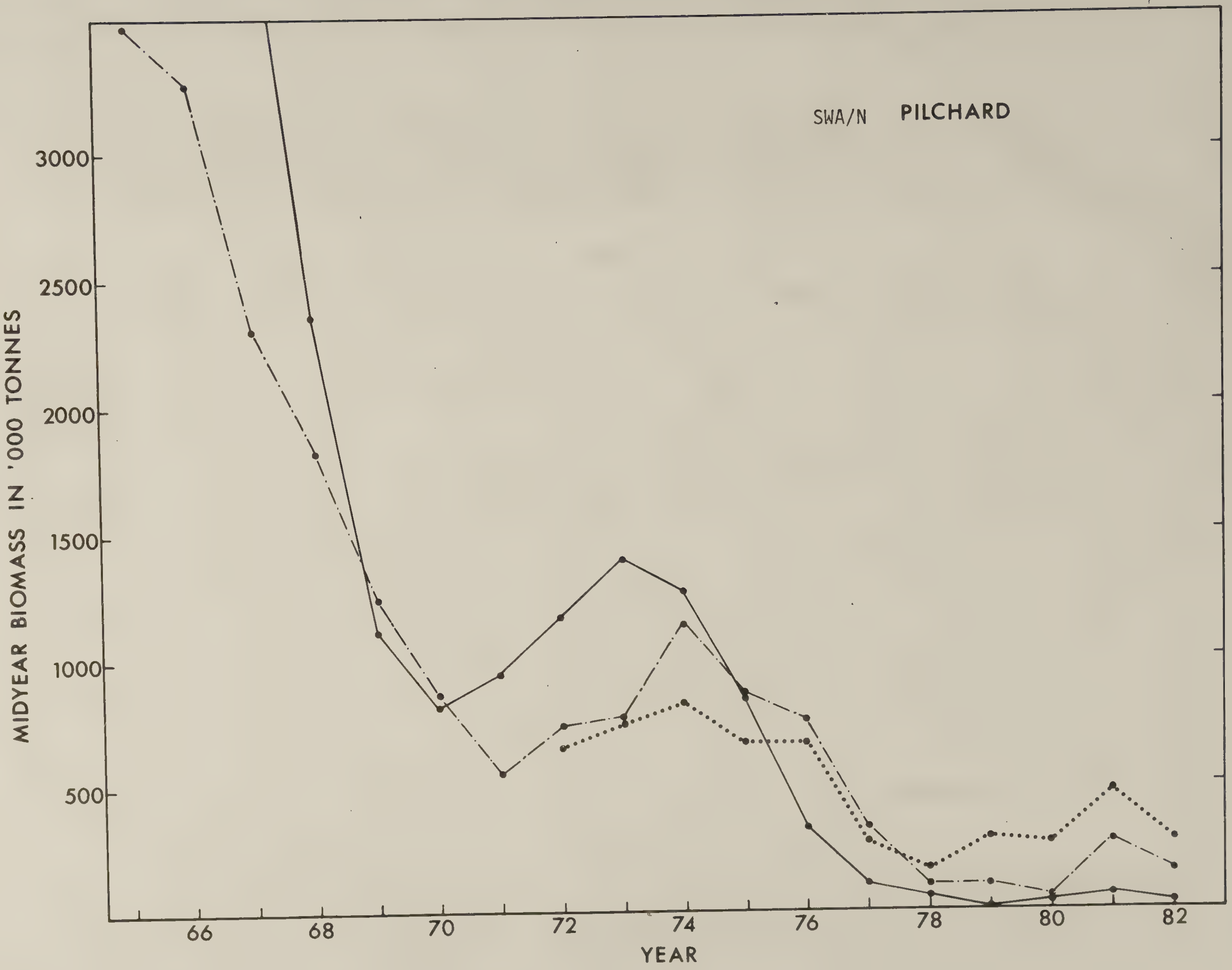


Fig. 12c. Comparison of VPA estimates of mid-year biomass (solid line) with CPUE indices for SWA/N pilchard. The CPUE indices have been renormalised to the average of the VPA biomasses over the periods 1964-1982 for SA and 1972-1982 for SWA/N. For SWA/N CPUE trends for two effort measures are shown: directed effort in tonne-hours (.......), and fuel issue (undirected) (-.-.-.-.).

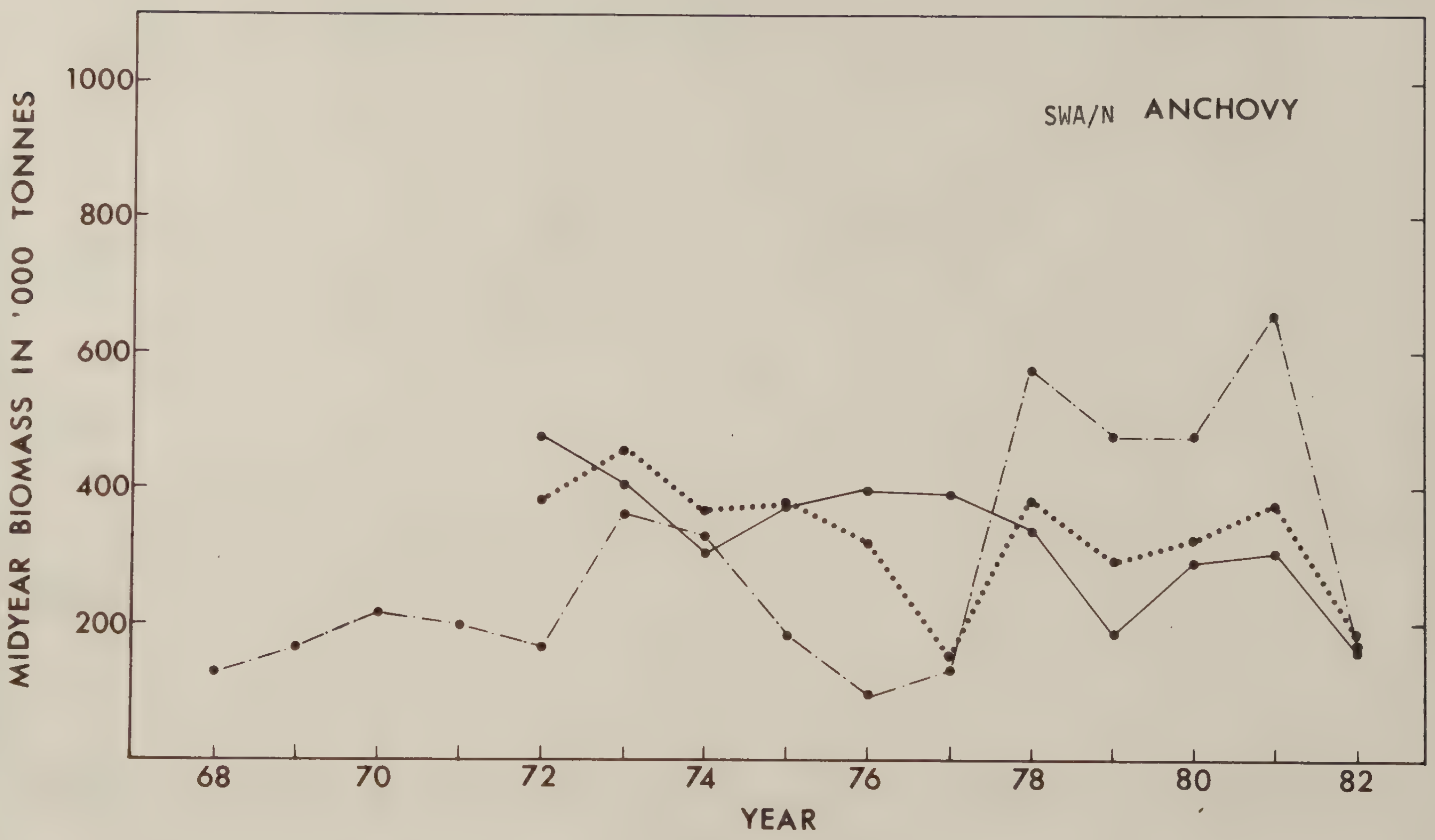


Fig. 12d. Comparison of VPA estimates of mid-year biomass (solid line) with CPUE indices for SWA/N anchovy. The CPUE indices have been renormalised to the average of the VPA biomasses over the periods 1964-1982 for SA and 1972-1982 for SWA/N. For SWA/N CPUE trends for two effort measures are shown: directed effort in tonne-hours (.......), and fuel issue (undirected) (-.-.-.-.).

Fig. 13a.
Plots of annual mean fishing mortalities $\bar{F}$ against E for 1964-1982 for SA pilchard. The 1982 point is indicated by a (x). A linear regression fit to the data is shown.

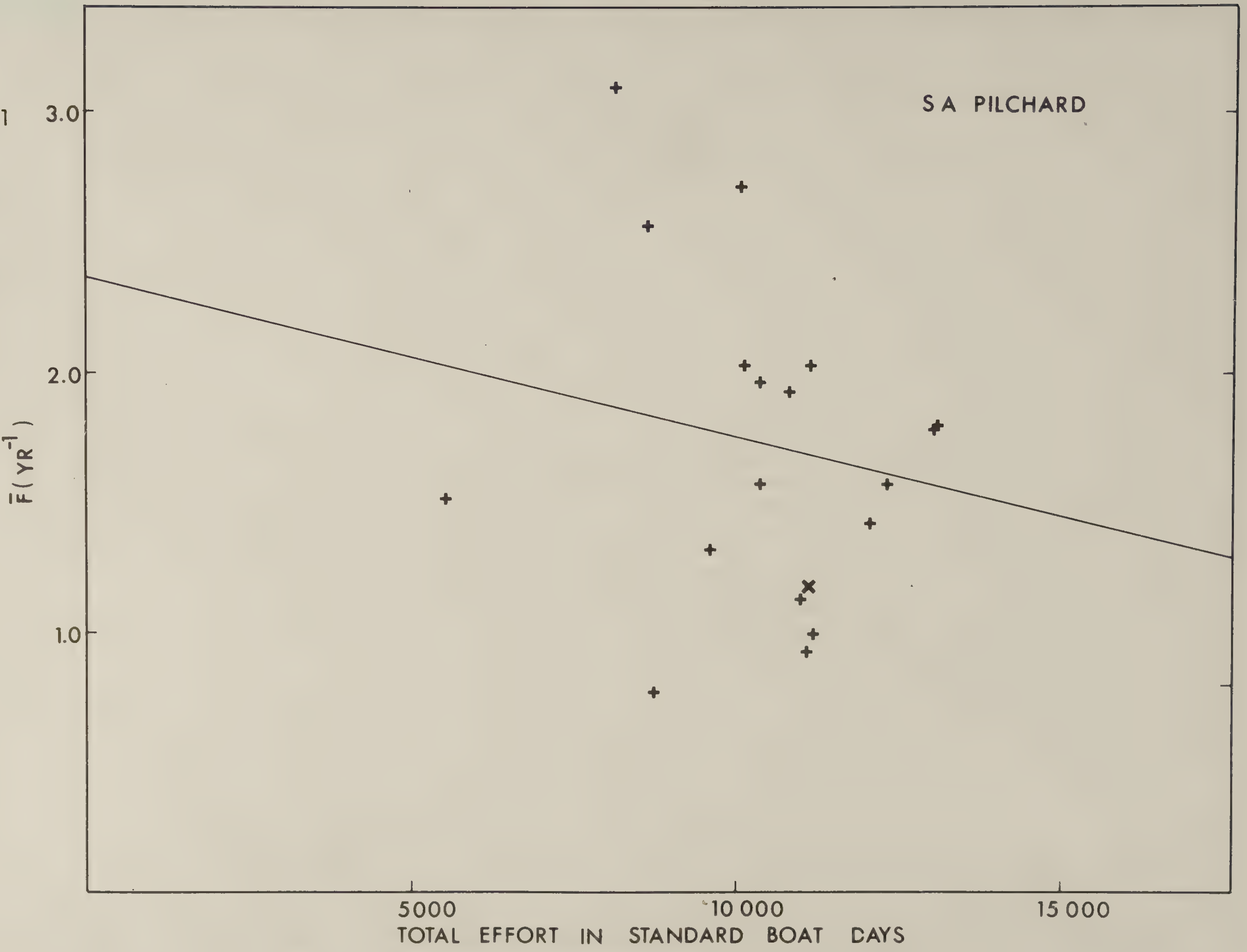
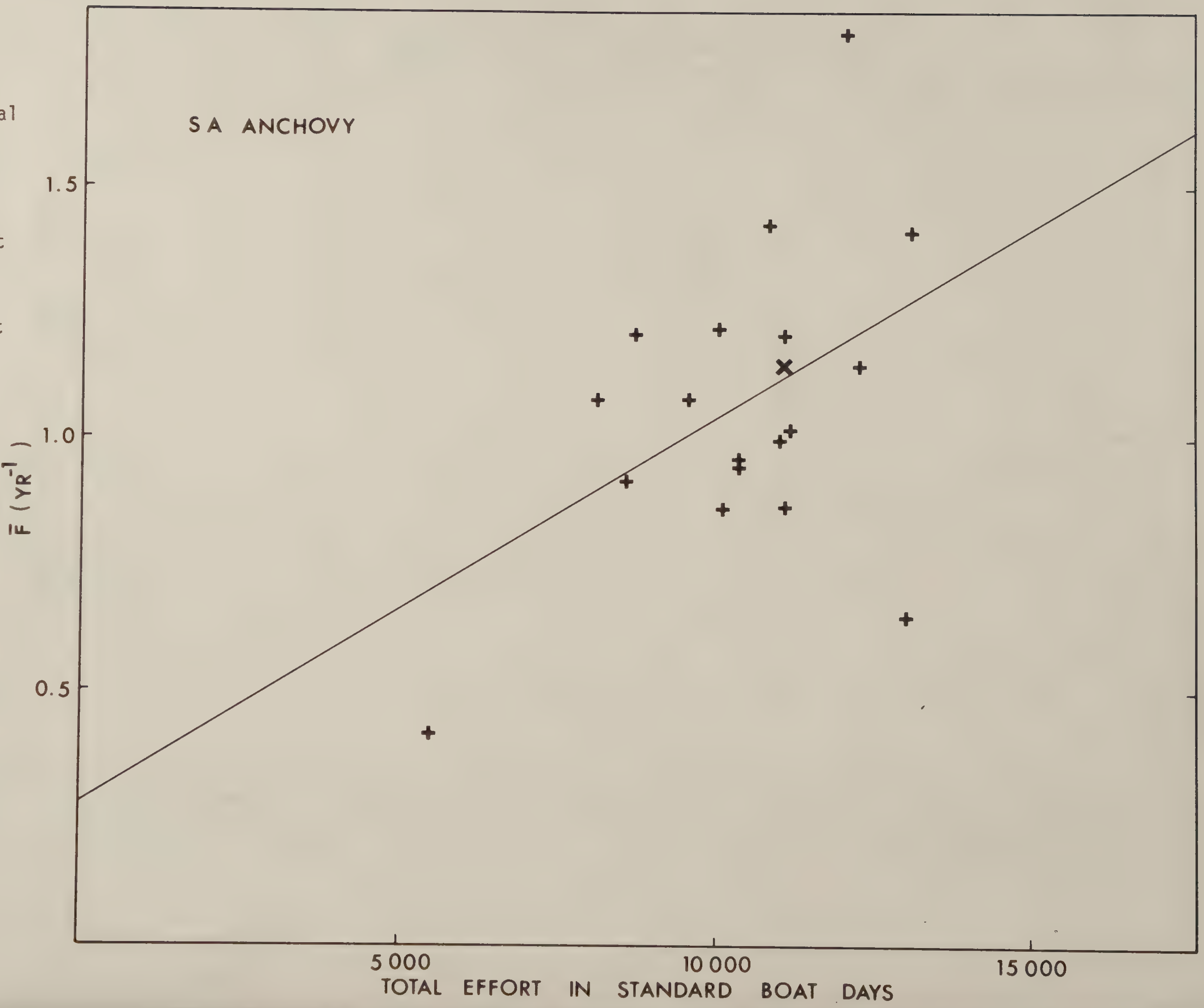


Fig. 13b.
Plots of annual mean fishing mortalities $\bar{F}$ against E for 1964-1982 for SA anchovy. The 1982 point is indicated by a (x). A linear regression fit to the data is shown.



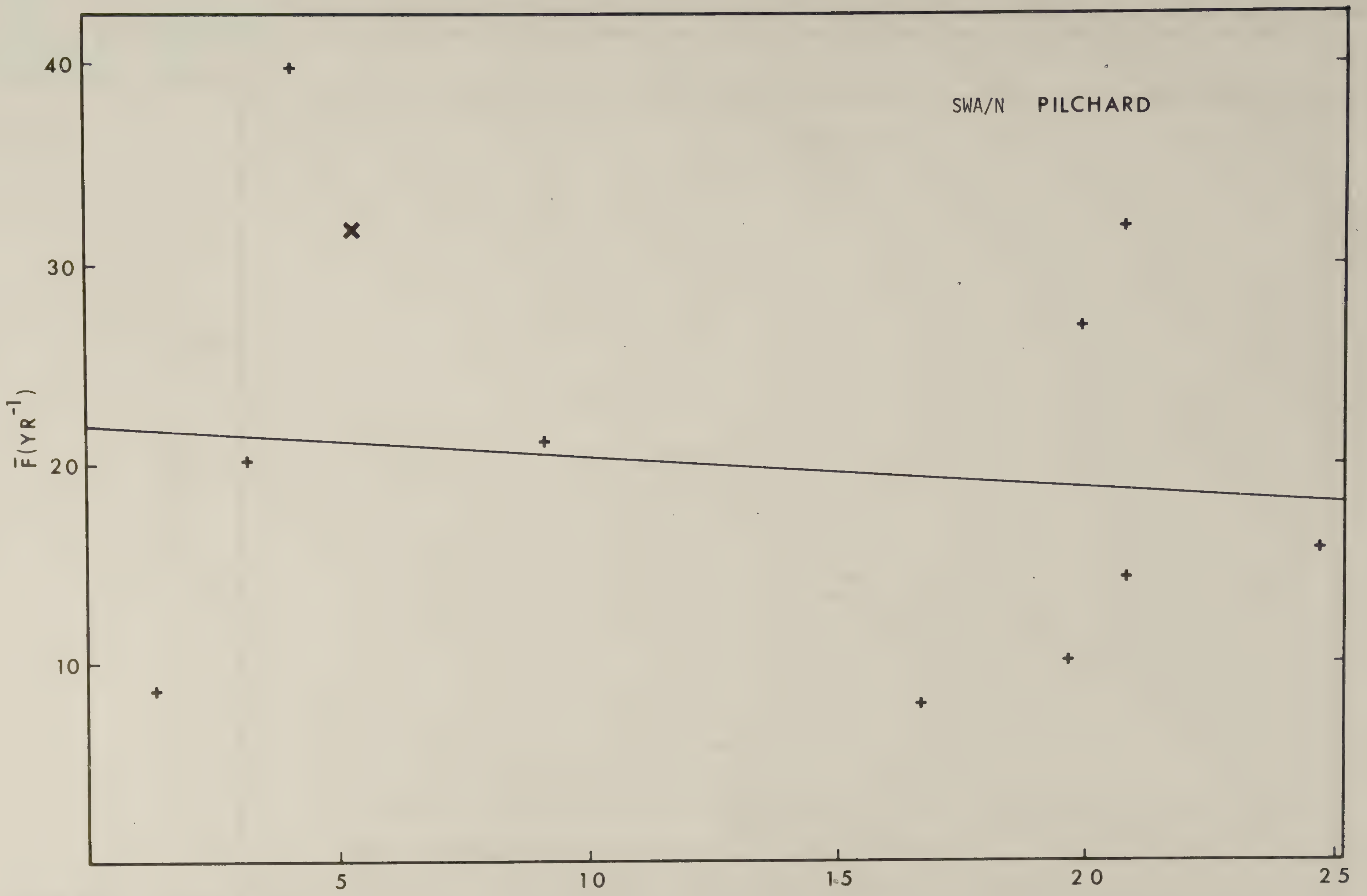


Fig. 13c. Plots of annual mean fishing mortalities $\bar{F}$ against E for 1972-1982 for SWA/N pilchard. The 1982 point is indicated by a (x). A linear regression fit to the data isshown.

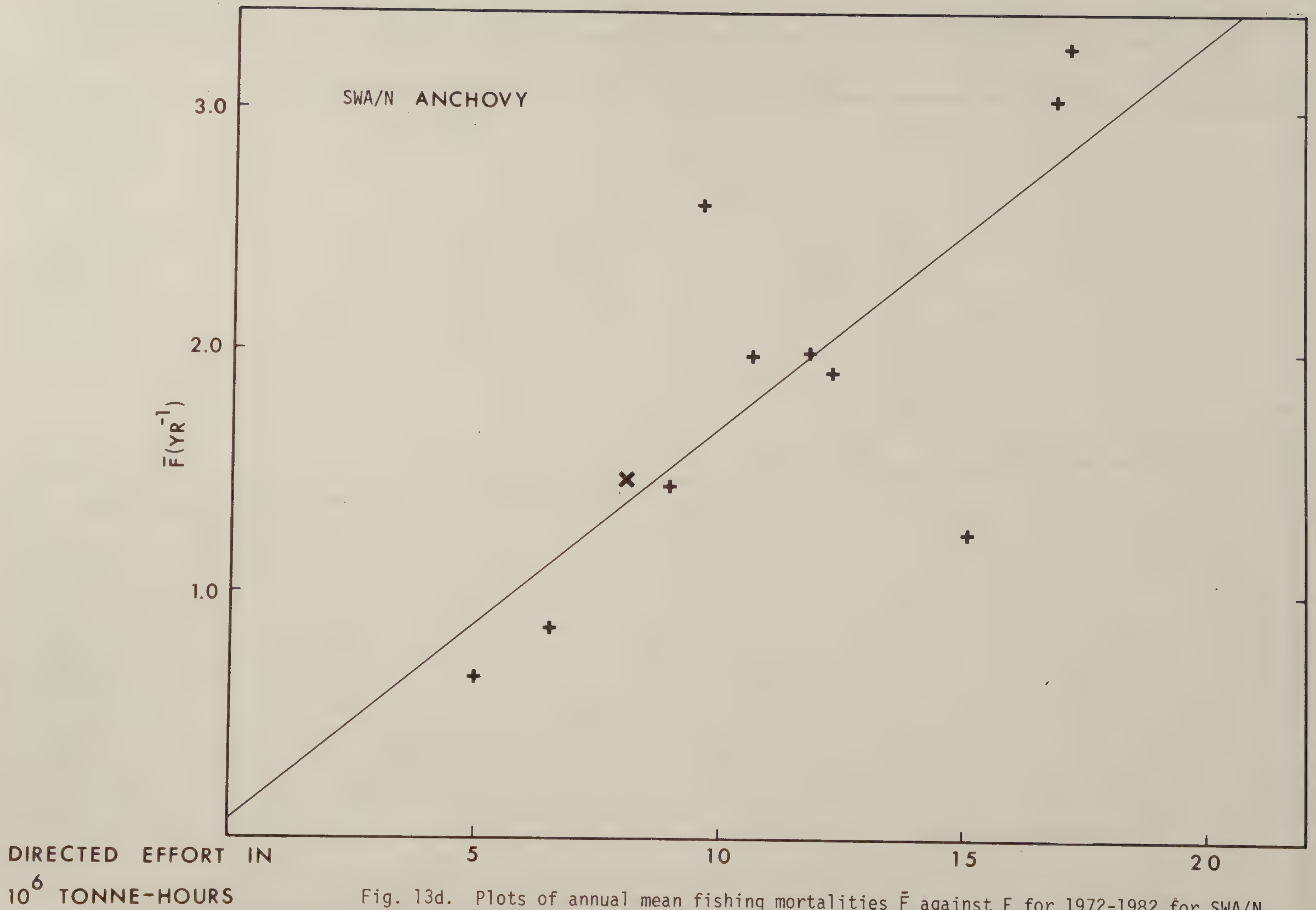


Fig. 13d. Plots of annual mean fishing mortalities $\bar{F}$ against E for 1972-1982 for SWA/N anchovy. The 1982 point is indicated by a (x). A linear regression fit to the data is shown.

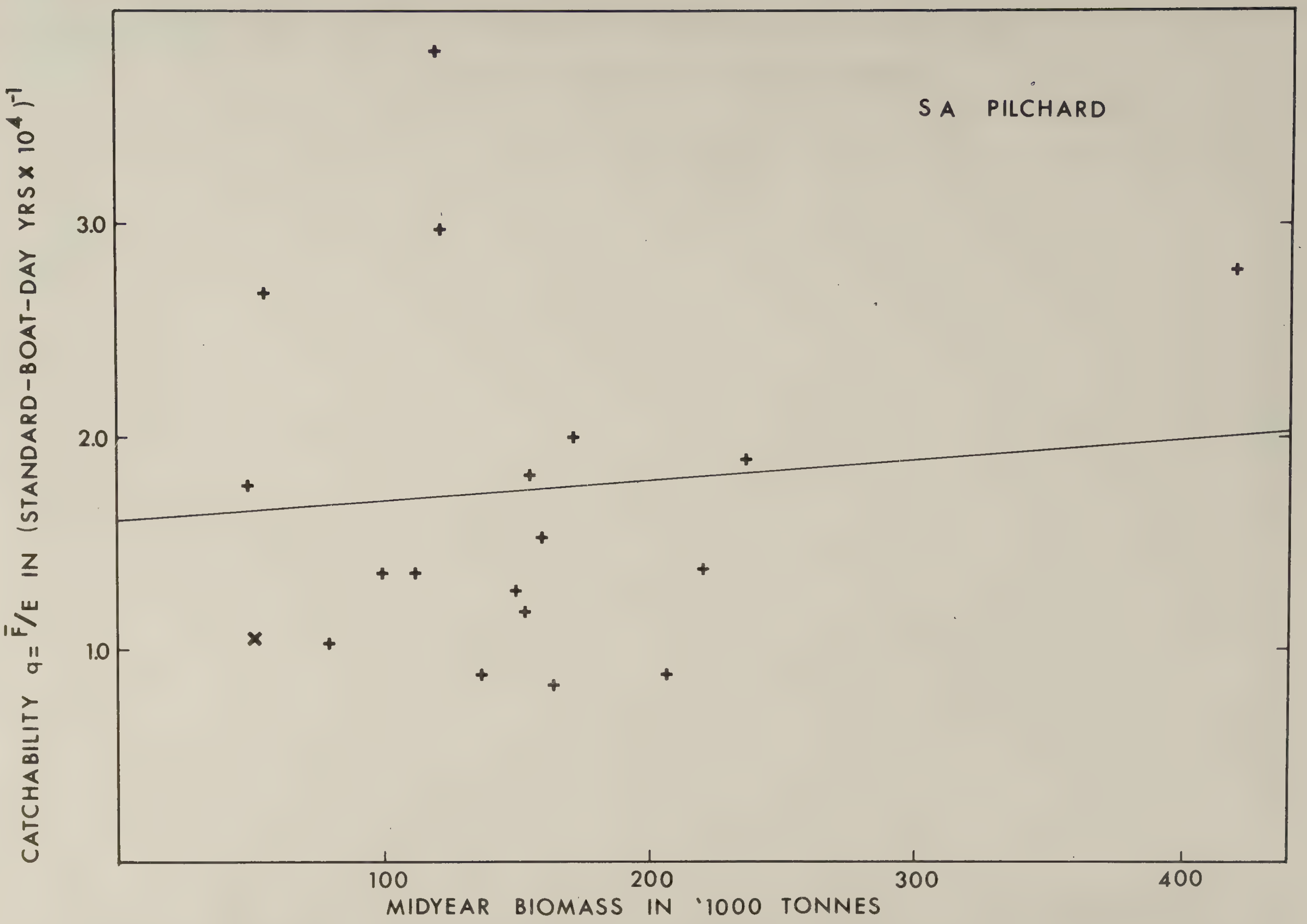


Fig. 14a. Plots of catchability $q=\bar{F}/E$ against mid-year biomass from VPA for SA pilchard. Effort measures and other conventions are as for Fig. 13.

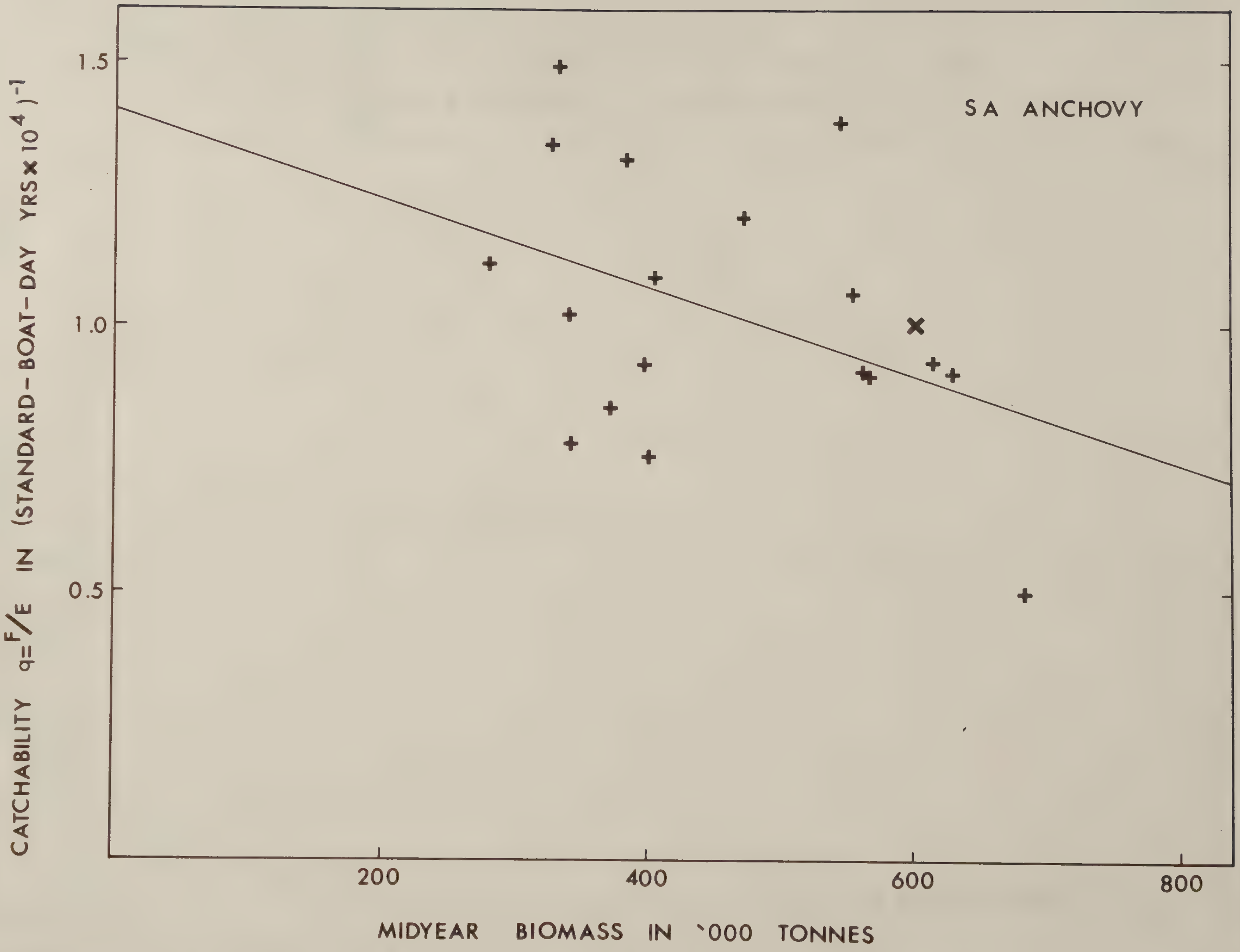


Fig. 14b. Plots of catchability $q=\bar{F}/E$ against mid-year biomass from VPA for SA anchovy. Effort measures and other conventions are as for Fig. 13.

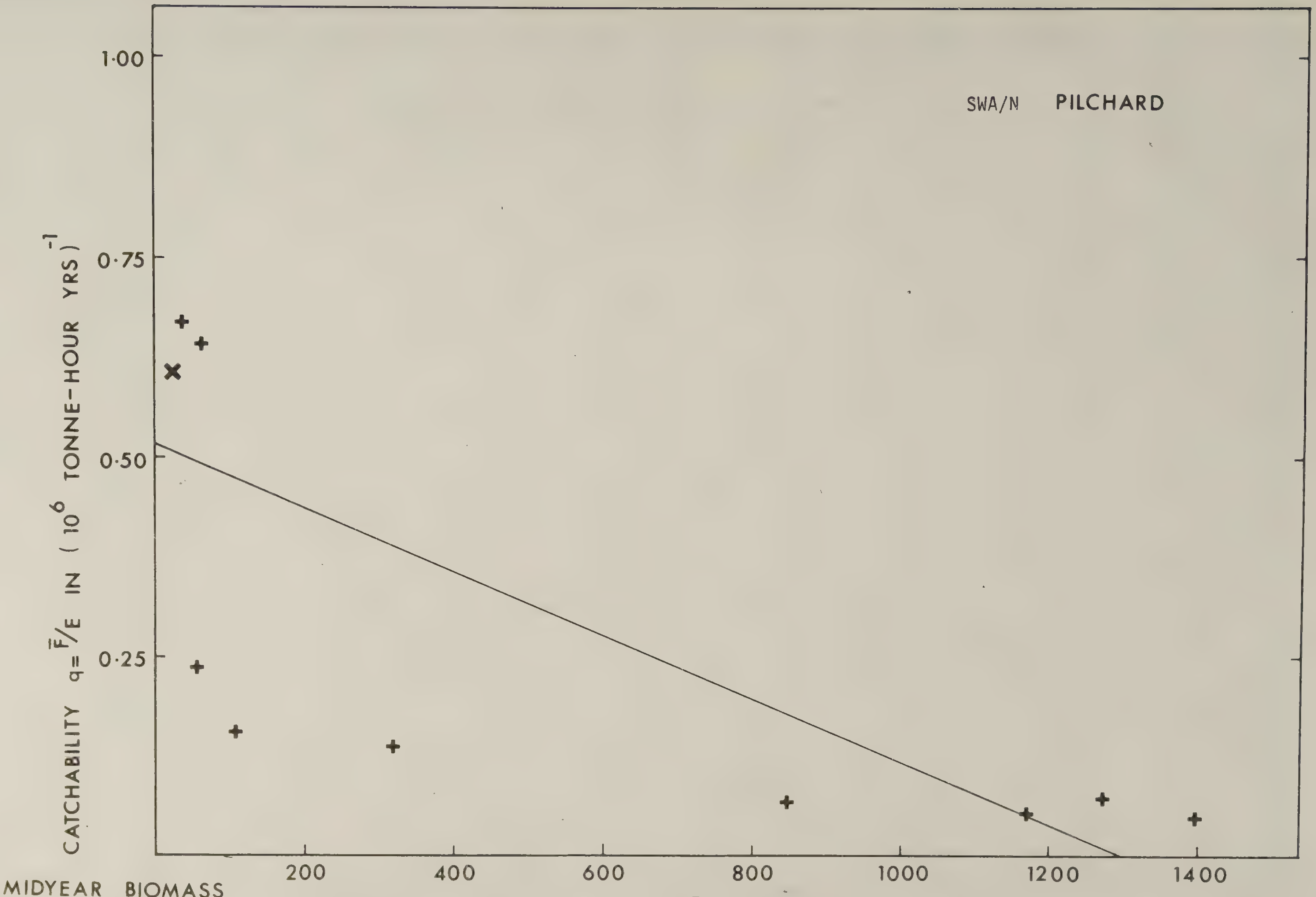


Fig. 14c. Plots of catchability $q=\bar{F}/E$ against mid-year biomass from VPA for SWA/N pilchard. Effort measures and other conventions are as for Fig. 13.

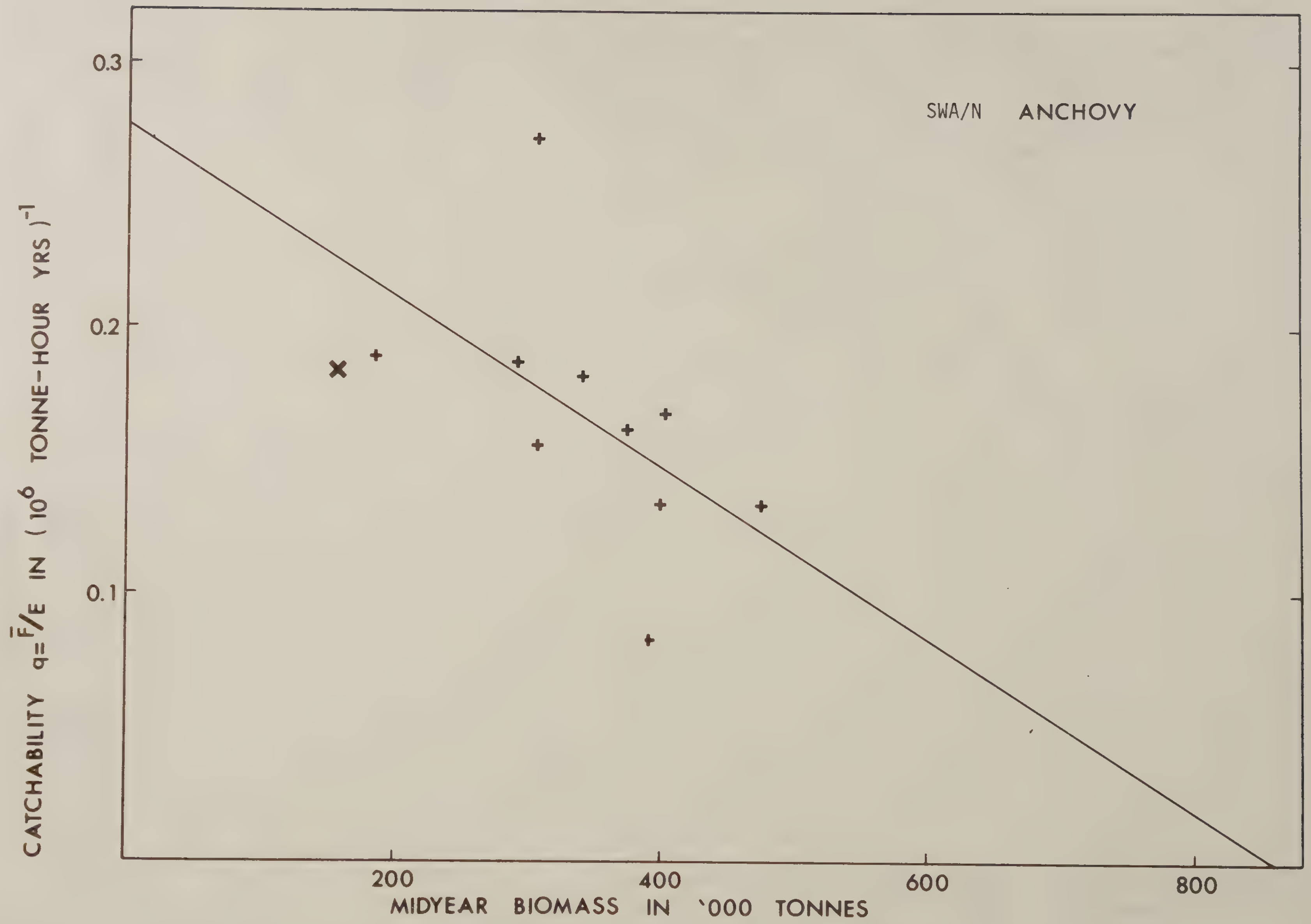


Fig. 14d. Plots of catchability $q=\bar{F}/E$ against mid-year biomass from VPA for SWA/N anchovy. Effort measures and other conventions are as for Fig. 13.

method used for effort estimation in this case yields CPUE values monotonically increasing with stock size, but there is no particular reason why the relation should be linear.

The poor relationship between $\bar{F}$ and E has important implications. The method indicated for current year fishing mortality estimation for VPA calculations may be unreliable (though this requires quantitative investigation), placing doubt on the important current biomass estimates the method provides.

While alternative effort measure providing improved correlations with $\bar{F}$ might be desirable, those used at present would nevertheless be roughly proportional to operating costs. There is no clear evidence from the data that larger stocks would provide proportionately higher catch rates, so that the economic rationale of a (temporary) quota reduction to supposedly achieve improved catch rates in due course is open to question.

The theoretical desirability for stability purposes of managing a pelagic fishery on the basis of constant fishing mortality rather than, say, constant quota is clear. If F is indeed proportional to E, the desired fishing mortality can be achieved by appropriate effort restriction. However, in the Southern African situation where there seems considerable fluctuation about such "relation", it is not clear that effort restriction alone could provide the necessary effect of adequately decreasing catches to compensate for a fall in stock size.

Table 7: Statistics of fits to data from VPA for the stocks under consideration.

| | ANCHOVY | | PILCHARD | |
|---|---|---|---|---|
| | SA | SWA/N | SA | SWA/N |
| Linear regressions | | | | |
| $\bar{F}$ vs E : r | +0.46 | +0.76 | -0.19 | -0.13 |
| q vs B : r | -0.41 | -0.53 | +0.10 | -0.68 |
| Stock-Recruit fits | | | | |
| Beverton-Holt Equation: $\bar{R}=$ | $\frac{160S}{130 + S}$ | $\frac{62S}{9 + S}$ | $\frac{26S}{220 + S}$ | $\frac{35S}{1600 + S}$ |
| Mean relative deviation | 0.22 | 0.19 | 0.50 | 0.59* |
| Serial correlation | +0.25 | -0.19 | +0.77 | +0.57 |
| Ricker Equation: $\bar{R}=$ | $0.73Se^{-S/450}$ | $0.57Se^{-S/300}$ | $0.064Se^{-S/950}$ | $0.022Se^{-S/2100}$ |
| Mean relative deviation | 0.22 | 0.24 | 0.66 | 0.58* |
| Serial correlation | +0.23 | -0.21 | +0.77 | +0.57 |

$\bar{F}$ = Average fishing mortality E = Fishing effort; q = $\bar{F}$/E = Catchability;
B = Mid-year biomass; S = Spawning biomass (000' tonnes);
R = Recruits (0-year-class strength in billions ($10^9$)); r = Correlation coefficient.
* Omitting very large 1980 value to preclude it swamping the others.

## Aerial and hydroacoustic surveys

Aerial observations supplemented by shipboard hydroacoustic data provided the primary abundance index used to monitor the SWA/N pilchard stock from 1972 to 1974.

The methods are described in Cram and Hampton (1976) and Cram (1977). Basically an aircraft, operating at night and observing shoals through bioluminescence, was used to map out the perimeter of loose aggregations of shoals ("shoal-groups"), and to calculate the proportion of this area covered by shoals. The role of the ship was to determine shoal thickness and packing density (number of fish per unit volume) by hydroacoustic means, together with species composition and fish mass from catch samples.

Biomass estimates were made using increasingly sophisticated applications of this technique from 1972-1974 (Cram and Agenbag, 1974 ). In Fig. 15 these are compared to VPA estimates of end of year biomasses (corresponding roughly to the midpoint of the survey periods). The estimates have been renormalised to provide the same average as the VPA estimates over the same period (a 55% reduction); packing density estimates were poor so absolute estimates are somewhat doubtful.

The extremely good agreement indicated in Fig. 15 must be tempered by the following facts. Errors of estimates are not shown, but the coefficient of variation was crudely reckoned at 50% (Hampton et al., 1979 ); also the choice of M=0.5 for VPA was in part influenced by producing similar biomass trends to the aerial surveys. Nevertheless in retrospect the performance of this survey method seems very promising, and it is most unfortunate that surveys were suspended in 1975 and 1976 precluding the important test of their ability to have detected the pilchard biomass decline. When surveys recommenced in 1977, the stock was too low to be able to apply the method for quantitative estimates.

The particular advantage in aircraft utilization is the large area coverage practical. Cram and Hampton (1976) indicate that over similar time periods, an aircraft surveys a surface area some two orders of magnitude greater than that insonified during a hydroacoustic ship survey. The method also relied on indications that most of the pilchard stock was observable by bioluminescence, and that most of what was seen was pilchard.

Regrettably prospects of using similar methods for anchovy do not appear promising (Agenbag, 1982). Inconsistent shoaling behaviour and the possibility that many shoals are not seen considerably increases variance. To provide an index of abundance (such as shoal area) from aircraft measurements alone, repeated surveys have to be undertaken for reliable results (i.e., to decrease variance), but would substantially increase costs.

Agenbag remarks that aerial observations, hydroacoustic surveys, and experimental catches in SWA/N during summer months all indicate too few anchovy shoals for reliable estimation procedures (possibly confirmation of VPA estimates (Figs. 6b, 6d) that indicate relatively low biomass over this period). This indicates winter surveys, but weather conditions then are generally less favourable for such work.

The most likely role for aircraft work on anchovy will be in a scouting capacity to identify areas of greater abundance and so assist plan stratification of hydroacoustics surveys.

Initial plans for hydroacoustics work in SA are for broad distributional surveys to identify anchovy concentrations for later stratification purposes, and stock boundaries. As the fishing fleet samples the fish nearest port rather than conducting a random survey, inferences on stock boundaries drawn from fishery statistics may be biased by the location of fishing harbours (Fig. 1). Consequently the proportion of the stock's biomass located north of latitude 31$^{o}$S or east of longitude 21$^{o}$E is unknown. Trawl samples carried out for species identification purposes during such surveys should also provide age structure information unbiased by the fishery.

Hampton (1982) discusses features of future hydroacoustic surveys. It is intended to use horizontal sonar (to obtain a wider range coverage) for shoaling fish, and vertical echo-sounders when fish are dispersed. While target strength estimation for absolute abundance assessment may prove difficult, the method should nevertheless be able to indicate relative stock trends. It is hoped that a coefficient of variation of less than 25% for an assessment from a 1-month survey can be achieved.

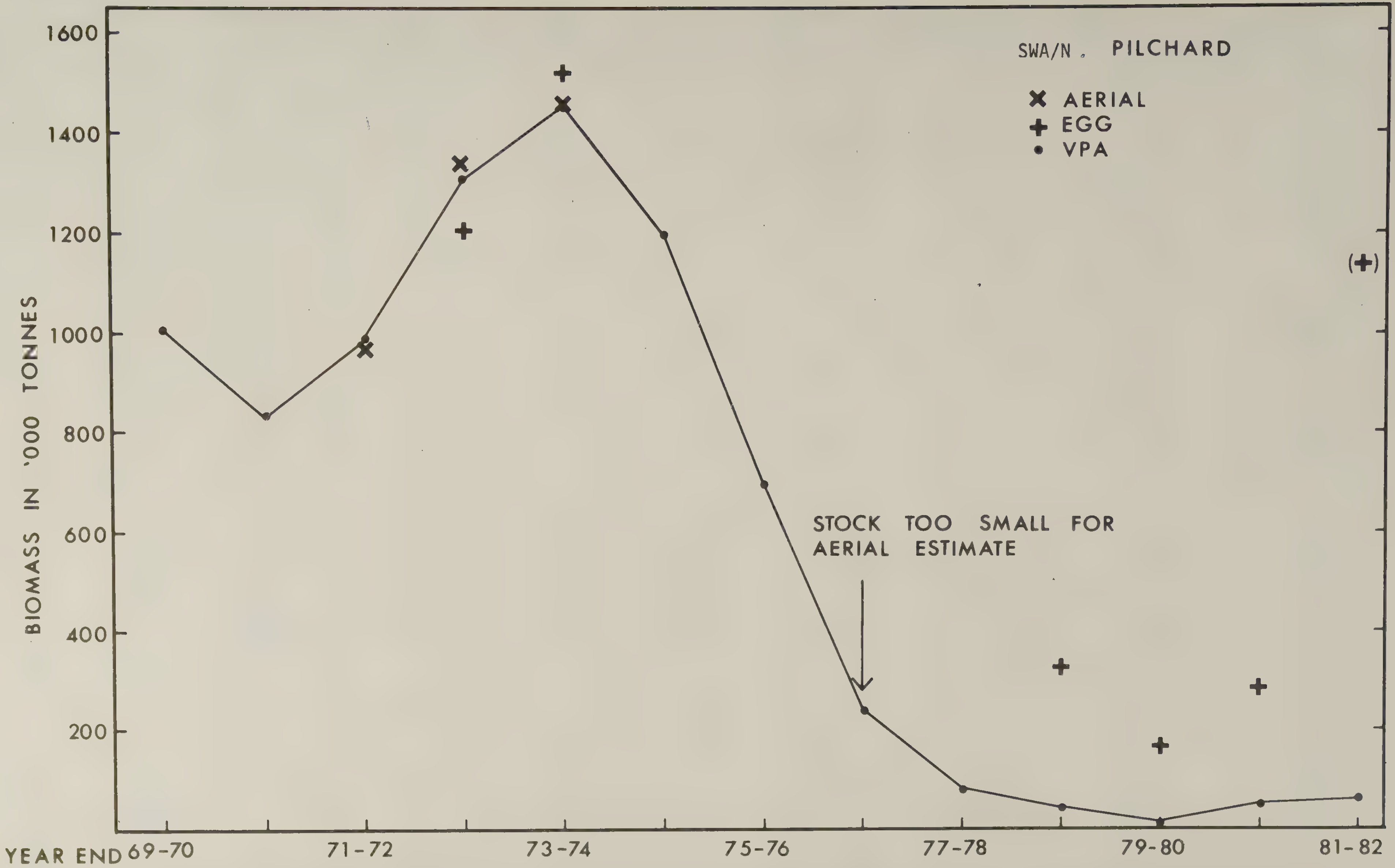


Fig. 15a. Comparison of end of year biomass estimates from VPA with those from aerial and egg surveys for SWA/N pilchard. The survey estimates have been renormalised to the average VPA biomasses for the corresponding years, excepting the 1981/82 pilchard egg estimate which is regarded as unreliable (see text).

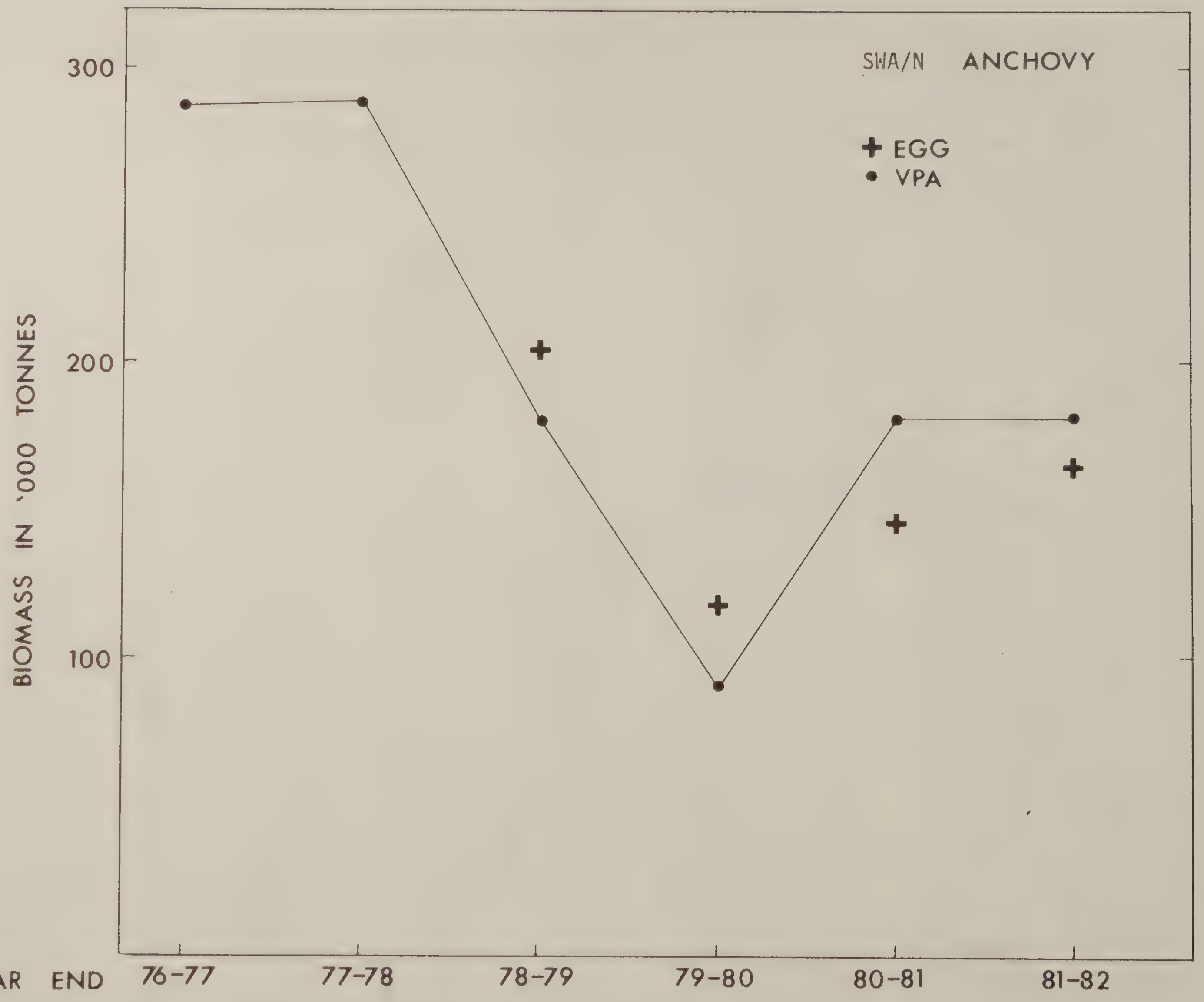


Fig. 15b. Comparison of end of year biomass estimates from VPA with those from egg surveys for SWA/N anchovy. The survey estimates have been renormalised to the average VPA biomasses for the corresponding years, excepting the 1981/82 pilchard egg estimate which is regarded as unreliable (see text).

Further utilization of multi-frequency techniques may permit distinction of adult and juvenile anchovy so that early estimates of recruitment strength (of particular importance for the anchovy where 0-year-olds constitute most of the catch) may become available.

## Egg and larval surveys

Intensive egg and larval surveys intended for quantitative assessment purposes commenced over the 1972/73 spawning season off SWA/N. Further surveys took place during the following season, but were then suspended until 1978/79; since then they have been carried out every year. Typically samples are taken at 1,000 stations spread over 5 cruises during the September-March period.

Estimates of total egg production over each spawning season have been made using an integration method (le Clus and Thomas, 1981, 1982; le Clus and Melo, 1981, 1982; le Clus, 1982). The intention has been to provide a measure of the spawning biomass that created the eggs, rather than an extrapolation from eggs to predict recruitment (because of the many, and variable effects playing a role between egg and recruit stages). As the number of occasions on which the fish spawn over the summer months is not known, the egg production figures have been used as a relative rather than an absolute index of spawning biomass.

Comparisons with VPA estimates of spawning biomass are shown in Fig. 15. Spawning biomass is taken as the biomass on 31st December, correspondingly roughly to the midpoint of the spawning season (i.e. fish assumed mature after 1 year - see VPA section). For comparative purposes egg estimates have been renormalised to the VPA average over the years surveys took place (excluding 1981/82 for the pilchard).

The plots show that the egg surveys produce the same trends as shown by VPA, but it is noticeable that the VPA calculated decline in stock is underestimated by the egg method. It seems plausible that this occurs through density dependent population responses. Shelton and Armstrong (1983) discuss changes in the SA pilchard and anchovy length (and thus presumably age) at maturity corresponding to stock size changes. Further Fig. 16 (Thomas, pers. comm.) indicates that mean gonad mass of the SWA/N pilchard shows an increasing trend with time. (Note this last refers to the catch as a whole and has yet to be adjusted for changing age structure for a more representative plot; the low 1981 figure for example corresponds to a year of low fishing intensity on older pilchard because canning was suspended for that year. In view of the mean age trend (Fig. 8), such correction would be likely to accentuate the trend.)

The effect of a drop in the age at maturity and gonad mass increase as the biomass declined would be to improve the agreement between VPA and egg estimates of the spawning biomass of the SWA/N pilchard shown in Fig. 15a. Nevertheless, this implies that egg surveys, taken at face value, can underestimate stock declines because of compensatory mechanisms.

A major problem with these egg surveys has been the very skew distribution of eggs per sample. A very few large samples have a considerable influence on the final estimates; though variance calculations have yet to be carried out, coefficients of variation seem likely to be rather high in consequence. (For this reason, the 1981/82 estimate for pilchard is regarded with some suspicion; the surveys conducted that season were less intensive than usual.) At present experiments aimed at replacing Bongo nets with the smaller Calvet nets are in progress; it is hoped that a greater number of small sized samples may counter this difficulty.

The method is a valuable monitor of the SWA/N pilchard stock where current small catches may be unrepresentative; however it is of less value for anchovy where recruitment accounts for a much larger fraction of the catch.

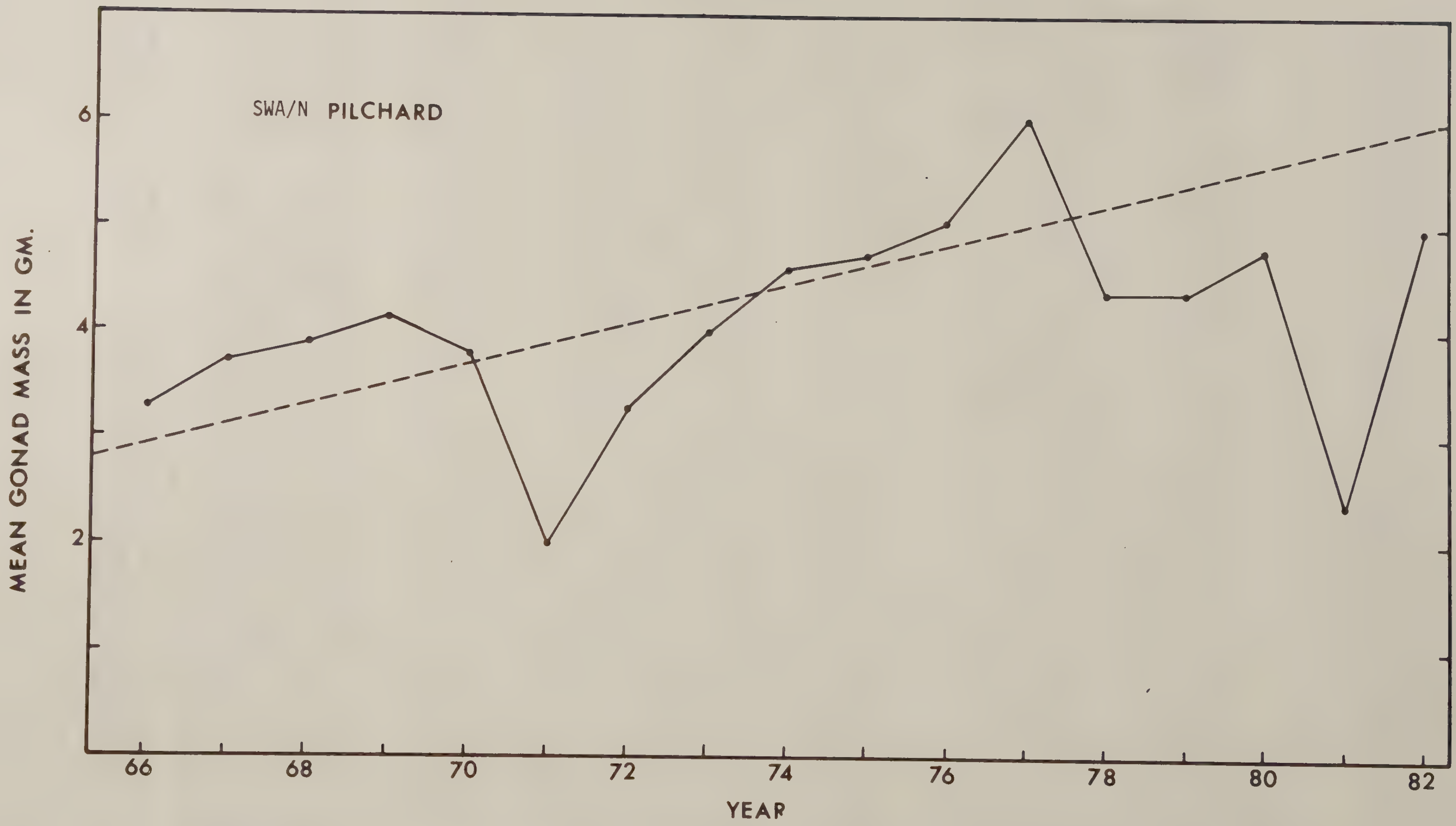


Fig. 16. Trend in mean gonad mass of the SWA/N pilchard catch (uncorrected for catch age structure). A linear regression fit is shown (r = +0.14).

## Tagging

Between 1956 and 1966 some 75,000 pilchards were tagged in SA waters, and 150,000 off Walvis Bay. Newman (1970a) analysed the SWA/N returns for stock estimation purposes, obtaining values of 5.6 million tonnes for the period 1957-1960, and 6.8 million tonnes for 1963-1966.

The change in tag return rates with time provides a reasonable estimate of the total mortality into Z (plus any emigration rate):1/ 0.7-0.8 in Newman's analysis. Population estimates however depend on evaluating the contribution of fishing mortality rate F to Z. This depends crucially on the initial tagging mortality proportion, and can also be confounded by failure to return tags recovered. Newman's estimates were based on an initial tagging mortality value of 40% reported for the Californian sardine.

Unless initial tagging mortality can be directly established, the tag return method seems capable only of providing an upper limit for stock size (some 10 million tonnes for the SWA/N pilchard over the 1957-1966 period). Z estimates from the change in tag return rate with time (assuming no significant sustained tag-loss/mortality rate) can however provide an independent check on ageing and an upper limit for M.

## Historic indices

Two methods have been used in Southern Africa to investigate stock trends prior to the development of commercial fisheries: scales in sediment cores and guano deposits.

a) Scales in Sediment Cores

Thomas (1982) reports on a feasibility study in which an area off Walvis Bay known to have anoxic sediments was sampled. Unfortunately no consistent trends appeared between cores. Thomas concludes that deposition does not proceed regularly enough to provide a stable record, probably due to periodic bottom disturbance.

Nevertheless pilchard scales (90%) were by far the most common in the samples, and there are indications from one long core that anchovy presence may be as recent as 400 years, possibly coinciding with climatic warming at that time. (Anon. 1982).

b) Guano Deposits

Guano deposits on islands and platforms have been shown to correlate with trends in major pelagic stocks off Southern Africa, and are discussed in Crawford _et al_., (1983). Of particular interest are the indications of substantial stock fluctuations prior to the onset of the fisheries.

The difficulty in using predator indices as estimates of stock size is (similarly to fishing effort) whether the functional relationship, (plausibly monotonic) is linear, and how to separate out multi-species effects. In this case the mechanism is complex as Bergh (1983) has shown that the deposit increase rate is at times much larger than possible for the bird species concerned, and so cannot be a function of bird numbers alone. Nevertheless predator indices are useful in providing at least a qualitative indication of stock trends.

Bergh (1983) shows that using guano deposits at Bird Island, Lamberts Bay on the SA west coast as a measure of pilchard recruitment, and subjecting this to natural and fishing mortality estimates (from VPA), provides a time series of biomass of pilchards of 3 years and older which correlates with guano deposits at Bird Island, Algoa Bay (Figs. 1, 17). This supports the migration theories for the SA stocks referred to earlier (Crawford _et al_., 1980; Shelton and Hutchings, 1982).

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1/ Assuming no significant change in selectivity over the age range involved.

This suggests that current Bird Island Lamberts Bay deposits might be useful as an anchovy recruitment index, though unfortunately the data would be available after rather than before fishing of the recruits began in a normal fishing season.

## Stock definition

Davies (1956) first suggested a connection between pilchards caught off SA and SWA/N speculating that the latter migrated from the Western Cape coast northwards to Walvis Bay. However Newman's (1970b) tag return analysis showed no recoveries in SWA/N of pilchards tagged in SA, and only very few of those tagged off Walvis Bay recovered in SA. Newman concluded independence of the two stocks, and assessment and management has traditionally treated the SA and SWA/N fisheries separately.

However the heavy reliance of the SWA/N fishery (since the 1977 pilchard collapse) on the "anchovy run", which consists almost entirely of 0-year-old fish which appear off Walvis Bay over the May-August period, has emphasised the importance of the origin of these fish.

Recent egg and larval surveys off SWA/N indicate that most of the anchovy spawning takes place to the north of Walvis Bay (Butterworth, 1980; le Clus and Melo, 1982; le Clus, 1982), and that eggs and larvae are carried further north and offshore by the prevailing currents (Badenhorst and Boyd, 1980). If this is the case it is difficult to see how adult anchovy which are fished well to the north of Walvis Bay can parent the mid-year "anchovy run", though transport of larvae southward by an undercurrent beneath the thermocline has been suggested (Anon., 1982).

The very high proportion of 0-year-olds in the "anchovy run" indicates it unlikely that this is an entirely resident self-sustained phenomenon, and the alternative possibility that is a component of the SA anchovy stock has been raised. Badenhorst and Boyd (1980) argued that larval transport from the Western Cape was possible, and Boyd and Hewitson (1983) suggests that larval distributions indicate the anchovy nursery area north of Lamberts Bay (lat. $32^{o}$S) extends as far north as Luderitz in SWA/N (lat. $26^{o}30$ S).

Little relationship between stock and recruitment is apparent from VPA (Fig. 7d), and unrealistically large F values for 0-year-olds for the SWA/N anchovy may also indicate that the catch is drawn from two stocks. Fishermen tend to support the two stock hypothesis and report that the "anchovy run" shoals move south to join the SA system (Anon., 1983b) Thomas _et al_., 1982, however monitored shoal-group movement from daily catch positions and found _no_ general southward migration over the period April to July 1978.

Little is known of the anchovy distribution between Lamberts Bay and Luderitz because fishing activity in the area has been minimal. On one occasion (1978/79) acoustic surveys detected what were considered substantial and persistent concentrations in the Orange River vicinity (lat. ± $28^{o}$-$29^{o}$S), which were subsequently identified as juvenile anchovy (Butterworth, 1980a).

Future hydroacoustics surveys should shed more light on this problem. Electrophoretic work is also in progress; preliminary results based on only a few samples are inconclusive regarding genetic distinguishability of SA and SWA/N anchovy stocks (Grant, pers. comm.). Following apparently poor anchovy recruitment in SWA/N in 1983 (le Clus and Melo, 1983), the 1982/83 egg survey results will be of particular interest. If the SWA/N fishery indeed exploits one anchovy stock only, a low result from the survey would be expected.

The number of anchovy stocks on the Southern African west coast, and the location of their effective dividing lines, remains unresolved. This has management relevance particularly for the SWA/N anchovy, for if the "anchovy run" arises from a small resident parent stock rather than comprising the northern boundary of substantial migration from the south, a more cautious management approach is indicated.

## STOCK TRENDS AND FUTURE MANAGEMENT IN THEORY AND PRACTICE

### Stock Trends

a) SA Pilchard

The principal feature of the VPA trend in Fig. 6a is the biomass peak in 1960 resulting from strong year classes from 1956 to 1959. Conventionally the pilchard fishery is seen as having expanded as the stock increased due to these year classes, then crashed as recruitment declined to average-to-poor values in the early 1960's.

The rise in biomass over the late 1950's is consistent with egg production indices (Stander and le Roux, 1968) from 1954-1964, though the area then surveyed was small. Guano deposits on Bird Island, Lamberts Bay (Fig. 17) also indicate the recruitment increment suggested.

On the other hand total guano production was relatively constant over the 1950's (Crawford et al., 1983), but fell markedly marginally in advance of the collapse in the pilchard catch. The VPA uses age data for the 1950's based on samples taken in 1965-1967 (after the collapse) (Fig. 2). It seems possible, in view of density dependent effects referred to previously, that at the higher biomass levels for the 1950's, growth rates would have been slower, so that age has been underestimated. This in turn would result in the VPA producing higher biomass levels for the 1950's.

Thus the biomass rise of the late 1950's may not have been as marked as indicated in Fig. 6a, and the collapse a more classical case of catches rising beyond sustainable yields coupled with poor recruitment leading to a rapid stock decline.

Subsequent to the collapse the stock has shown only one small upsurge following good recruitment in 1973 which was offset by a heavy catch in 1976. Over the past 5 years the stock seems to have declined to a level of only 50 thousand tonnes. The most recent estimates however are very sensitive to the prescription used for current year F estimation. Possible direction of fishing effort away from pilchard in 1982 could result in the procedure used underestimating the biomass present.

b) SA Anchovy

The only information on anchovy abundance prior to the commercial fishery comes from blanket net catches (Stander and le Roux, 1968). These suggest that anchovy substantially increased in abundance compared to pilchard over the decade 1955-1964, though sampling intensity was low particularly in the early years.

The VPA trend (Fig. 6b) suggests a near doubling of anchovy biomass from 1973 following good recruitment that year. This increase could be larger still in that the increase in length at maturity (Shelton and Armstrong, 1983) suggests slower growth rates recently, and hence older ages and larger biomasses for the 1970's. Armstrong (pers. comm.) advises otolith ageing of anchovy for recent years, though not yet considered entirely reliable, does indicate an older age structure for present anchovy catches than does the age length key based on 1965-1967 scales (used for the assessments of this paper), which is consistent with this hypothesis. However the increase in landings to 300 thousand tons over the past 4 years coincides with a decline.

The current estimate depends on how the higher proportion of 0-year-olds in the 1982 catch is interpreted. It could reflect either good recruitment, or little remaining adult stock. The procedure used interprets it as the former, as CPUE has shown no marked decline, but previous discussion of the plots of Figs. 13 and 14 suggests this may not be a very reliable method.

The estimates suggest the anchovy is very heavily exploited at present. However an alternative viewpoint is that the age structure is not a reflection of a large Z through fishing mortality, but rather of a large emigration component (conceivably offshore and/or eastward) beyond the range of the fishery. The perhaps surprising stability of catches is then explained as the catch constituting only a small fraction of a much larger stock. Hopefully future surveys will allow discrimination of the alternatives.

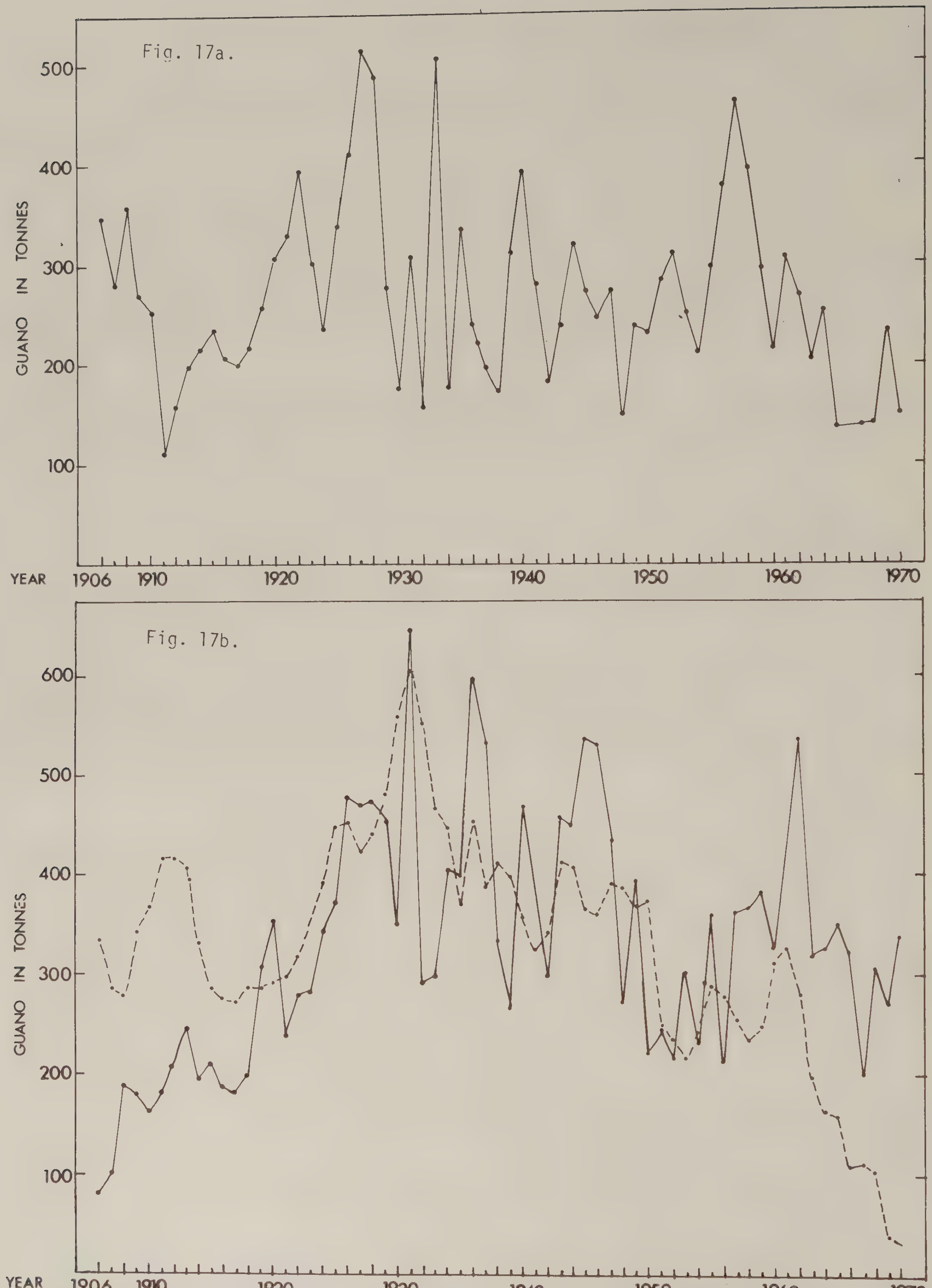

Fig. 17: The annual guano scrapings from a) Bird Island Lamberts Bay, and b) Bird Island Algoa Bay (——). The predicted biomass of pilchard aged 3 years or above calculated using a) as an index of recruitment, is shown in b) (---); units have been renormalised to the mean annual Bird Island Algoa Bay scrapings 1906-1970. The correlation coefficient for the two series in b) is +0.35.

c) SWA/N Pilchard

As with the SA case, knowledge of the stock trends prior to 1967 is confounded by the absence of ageing material. Though length distribution data is available, density dependent growth rates (see Fig. 9) seem probable and would distort trends if later period age-length keys were used.

Fig. 18a shows the adult pilchard modal length trend which appears a poor indicator of stock health without clear features corresponding to the two stock collapses. Also shown (Fig. 18b) is the trend in mean length (in excess of 21 cm) of fish longer than 21 cm. This always corresponds to the decreasing limb of the length distribution, and conceivably provides a rough index of mean age, and hence exploitation and stock level. This suggests a decline in the stock from the early 1950's, and further reaction to the increasing quotas of the 1960's.

Cram (1981) argues on the basis of CPUE with fleet hold capacity as a measure of effort that the stock was declining from at least 1964. Catch per fuel issue trends (Fig. 12c) also support this conclusion. Newman (1970a) shows that the area over which the fleet operated increased considerably from late 1950's to mid-1960's.

It seems most probable that the stock declined under increasing harvesting intensity in the 1960's from a biomass in the 5-10 million tonne vicinity, to less than 1 million tonnes by 1970. The partial recovery of the early 1970's was largely due to the strong 1972 year-class. Once this had passed through the fishery, followed by poor year classes in 1975 and particularly 1976, the fishery again collapsed under over-intensive harvesting.

Subsequent to this the average age of the catch has dropped even further (Fig. 18a), with fish over 3 years of age now seldom encountered (Fig. 19). (The contrary trend in Fig. 18b may arise through faster growth rate both from density dependent factors, and higher temperatures in the northern areas where adult pilchard are now caught.)

Though an upsurge in recruitment permitted a minor recovery in 1980/1981, indications of poor recruitment for 1982 (Thomas, 1983) together with comparatively large catches in 1981 and 1982 suggest the stock is back at a very low level (Fig. 6c).

The precise value is again very sensitive to the dubiously reliable procedure for current year F estimation. Paradoxically if pilchard dumping is continuing this could mean that the stock level is actually greater than that calculated through placing an underestimate of the true catch in the VPA. (For such an effect the proportion of the catch dumped would have to have increased to affect trends.)

Both pilchard stocks seem nevertheless to be in a predator pit situation with the fishery industry the predator. Any burst of good recruitment is rapidly countered by increased landings, and the piggy-back effect of a series of good year-classes that could lead to significant stock recovery never given the chance to develop. Unless effort on the pilchard can be substantially reduced, both stocks seem destined to produce roller-coaster-like biomass trends following the footsteps of the Californian sardine, conceivably to extinction.

d) SWA/N Anchovy

The biomass trend of Fig. 6d for the SWA/N anchovy is critically dependent on the assumption of a single SWA/N anchovy stock. Almost certainly the pre-1972 trend is spurious, being based on unrepresentative samples for length distribution.

Be that as it may, there is a general downward trend over the past five years, and caution seems indicated particularly following the 1982 recruitment failure (le Clus and Melo, 1983).

e) Stock-recruit relationships

These are given in Fig. 7. The "environmental" fluctuations may be represented by a parameter $\alpha$, where

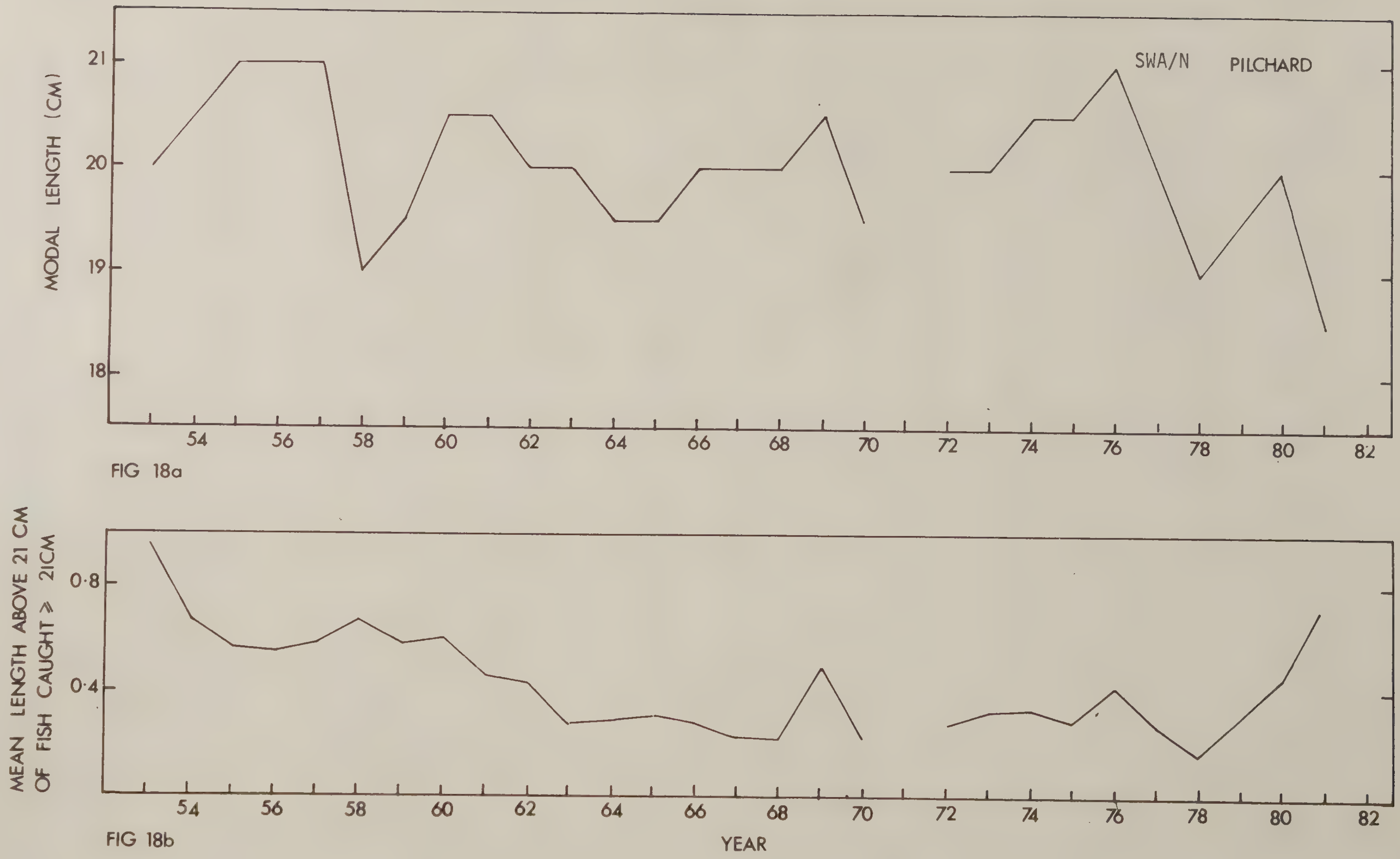

Fig. 18. Trend in (a) adult modal length, and
(b) mean length above 21 cm of fish exceeding 21 cm in length in the SWA/N pilchard catch.

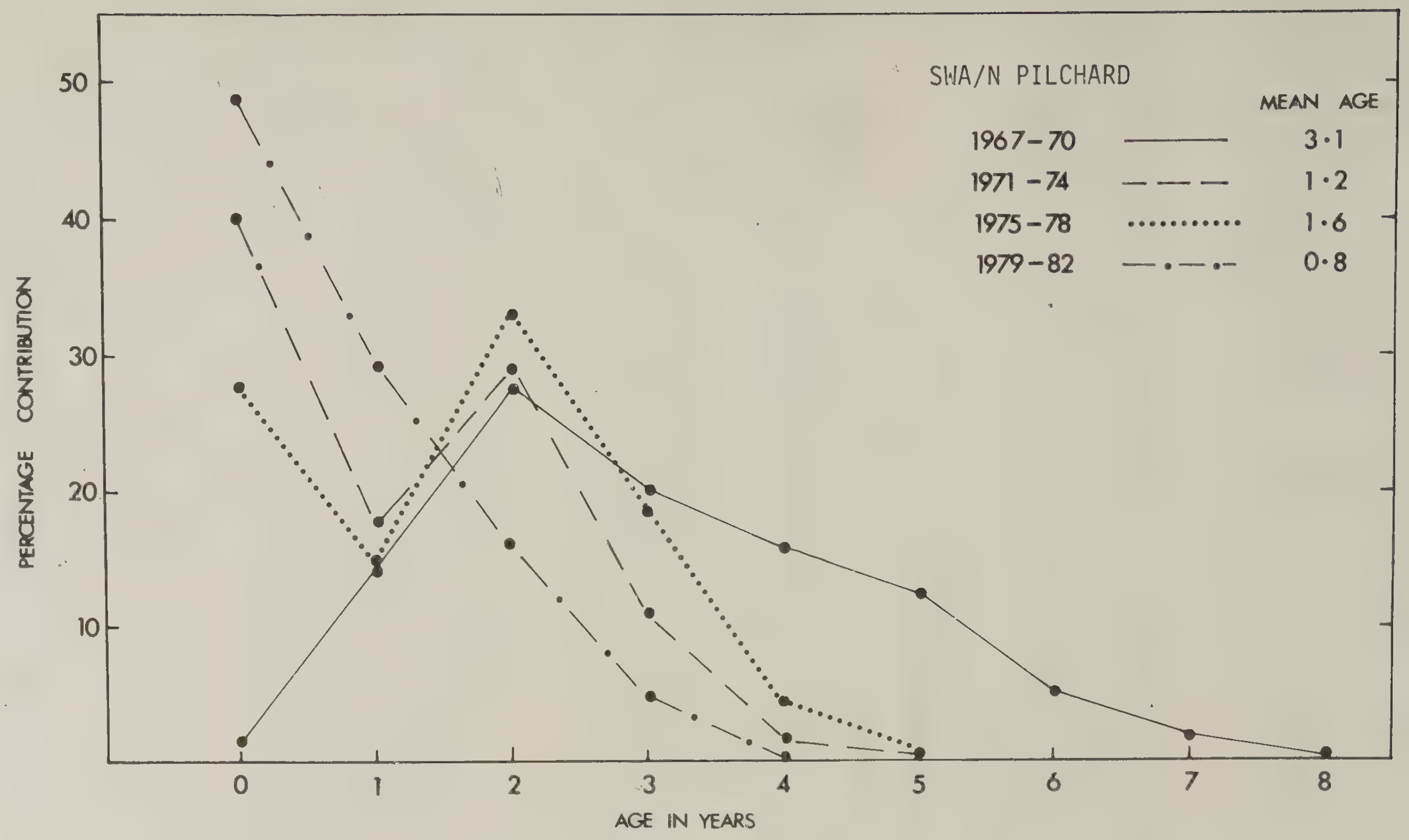

Fig. 19. Average age composition (by number) of the SWA/N pilchard catch over 4-year periods from 1967-1982.

$R_y = \alpha_y \hat{R}(S_y)$

$R_y$ = recruitment in year y

$S_y$ = spawning stock

$\hat{R}$ = stock-recruit relationship

Table 7 gives values for the mean $|1-\alpha_y|$ relative deviation and serial correlation for the $\alpha_y$ time series for each stock, which is shown in Fig. 20. Interesting features are that both are much higher for pilchard than anchovy, indicating (but not fundamentally explaining) greater anchovy stock stability. Considering the potential for fluctuation through the egg-larval stages, it is perhaps surprising that the mean relative deviation for anchovy is as low as 20%.

A further point of interest is whether the adult density dependent mechanisms noted previously can entirely account for the convexity of the stock recruit plots obviating the need for compensatory mechanisms at the egg and larval level. Recent calculations of phytoplankton production off the Western Cape (Shannon and Henry, 1983) based on satellite measurements are consistent with the observations of adult density dependence in that they imply food availability may be limiting.

## A Possible Basis For Future Management Recommendations

a) Sustainable yield estimates

Empirical production models using catch and effort data would seem of dubious value, primarily because of the difficulties with effort discussed earlier. Allowance for time dependence and skewness of the yield curve introduces further problems.

Rather, analytic models such as the Beverton-Holt yield per recruit approach appear more useful. However the likelihood of diminished recruitment should the parent stock be decreased must be taken into account. This may be effected by incorporating a stock-recruit curve (which is a best fit to the estimates of spawning stock and recruitment from VPA) into the Beverton-Holt analysis (Getz, 19 ).

In fitting, say, Ricker or Beverton-Holt equations to the data, one is not suggesting that only the particular mechanisms from which these functional forms are derived are the ones actually dominant. Rather the forms are empirically plausible (which means that the empiricism of catch-effort production models is not avoided but reappears at another level). Nevertheless identification of the mechanisms causing the convexity (density-dependence) of the curve is important for selecting the most appropriate minimization criterion for the best fit.

On the stock-recruit plot for the SA anchovy (Fig. 7b) a replacement line has also been drawn, corresponding to the recruitment required at a particular spawning biomass level to maintain the stock at that level in the absence of exploitation. The sustainable yield is then given by the difference between stock-recruit and replacement lines, apart from adjustments arising from lowering the average fish mass as the exploitation level rises.

Fig. 21 shows the result of such calculations for the SA anchovy, with sustainable yield plotted as a function of mid-year biomass. Age-specific selectivities from VPA fishing mortality estimates have been used in the calculations, with results shown for both Beverton-Holt and Ricker stock-recruit fits.

The variation of the associated MSY estimate with natural mortality is shown in Fig. 22. (The VPA is first carried out with the alternative M, leading to an amended stock-recruit relationship.) Interestingly the MSY calculated appears relatively insensitive to M between 0.8-1.3, the range considered possible.

Deterministic projections under various harvesting strategies are possible using this approach. The results for some fixed quota policies are indicated in Fig. 23.

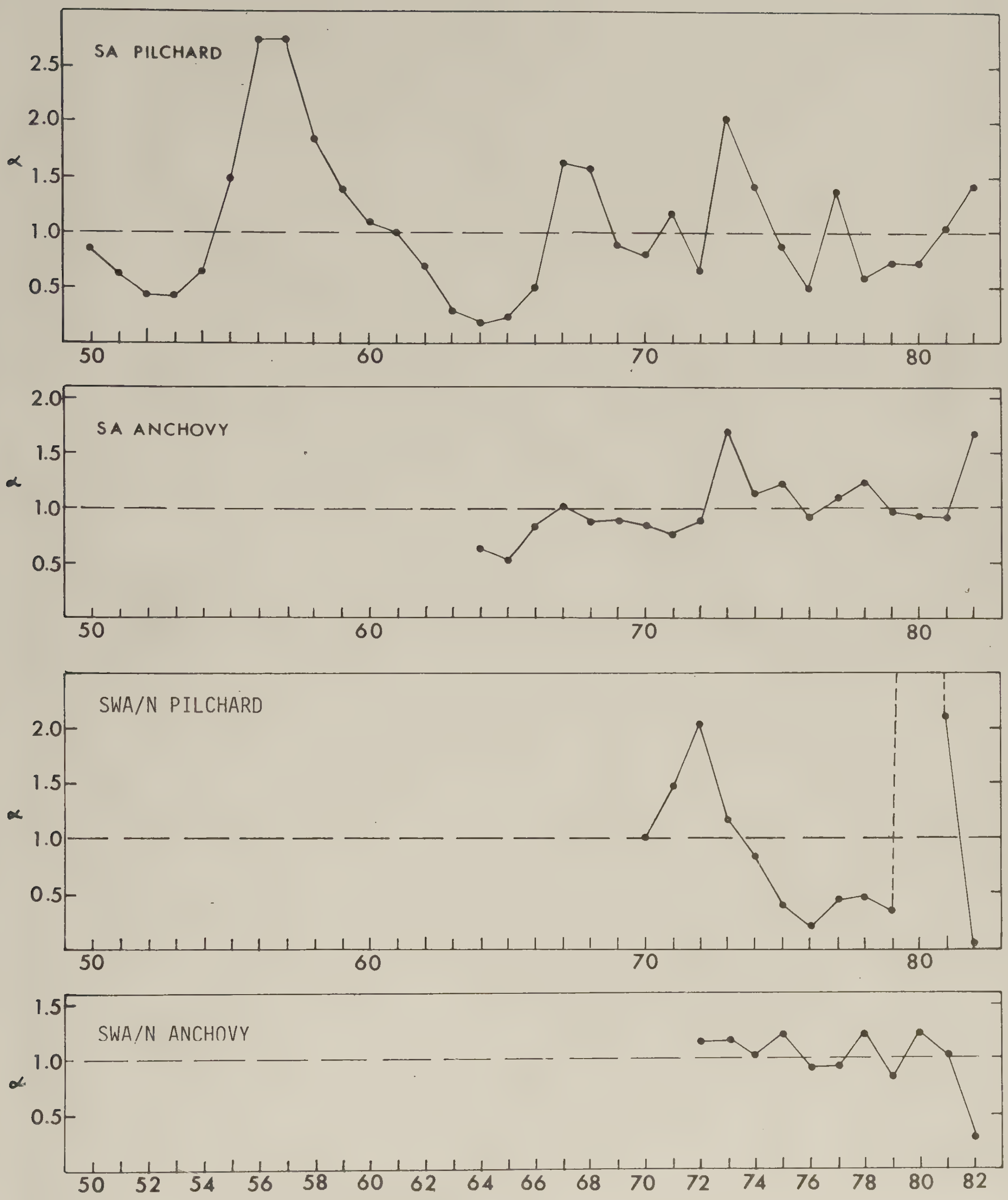

Fig. 20. Plots of $\alpha = {}^{R}/\hat{R}$ (see text) where $\hat{R}$ is as predicted by the Beverton-Holt stock-recruit fit to data for the stock concerned.

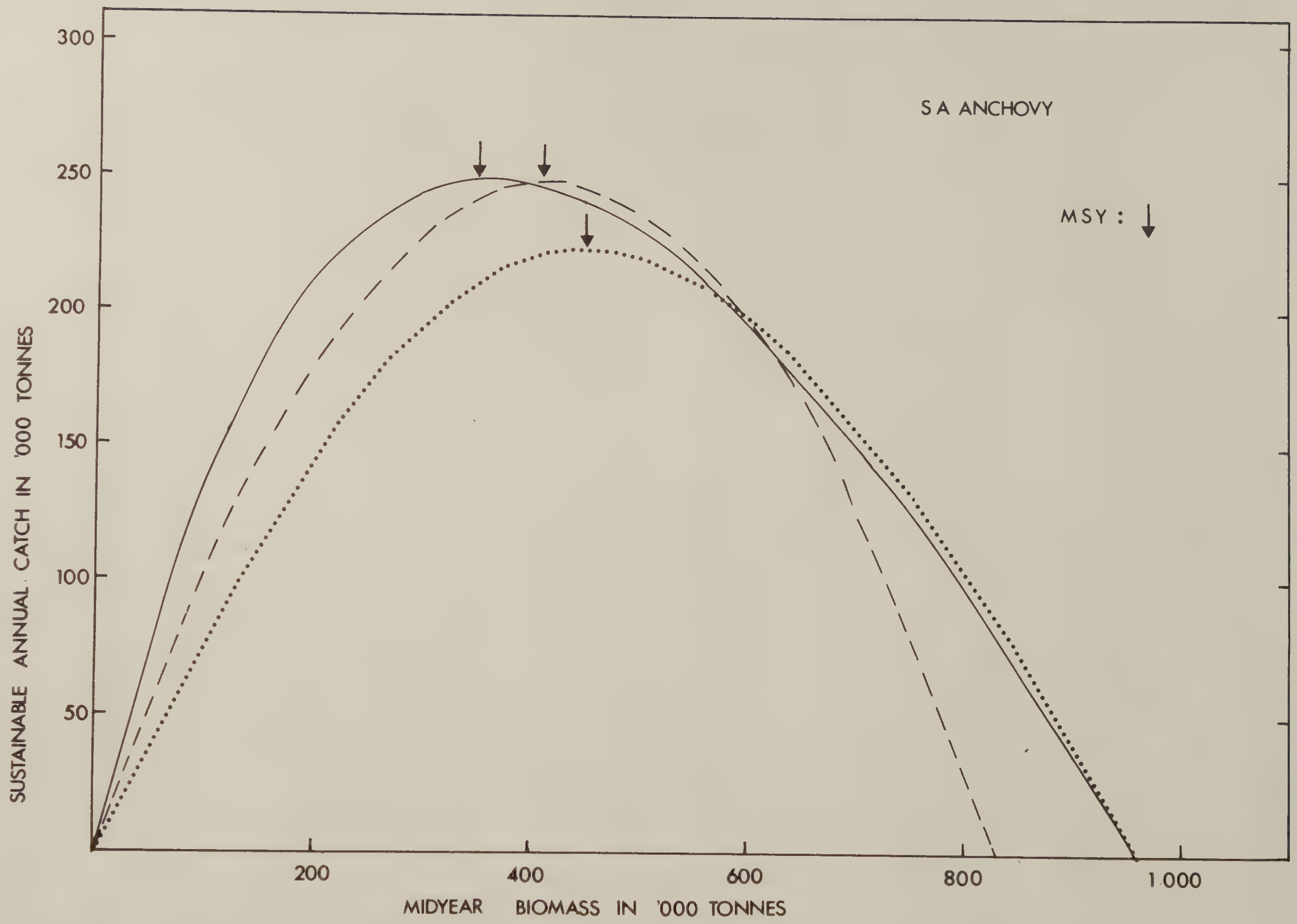

Fig. 21. Sustainable annual yield as a function of mid-year biomass for the SA anchovy. Curves shown are for the standard (January-August) season for Beverton-Holt (——) and Ricker (- - -) fits to the stock-recruit plots, and for the new (mid-October-March) season using the Beverton-Holt fit (.....). All calculations take M=1.1.

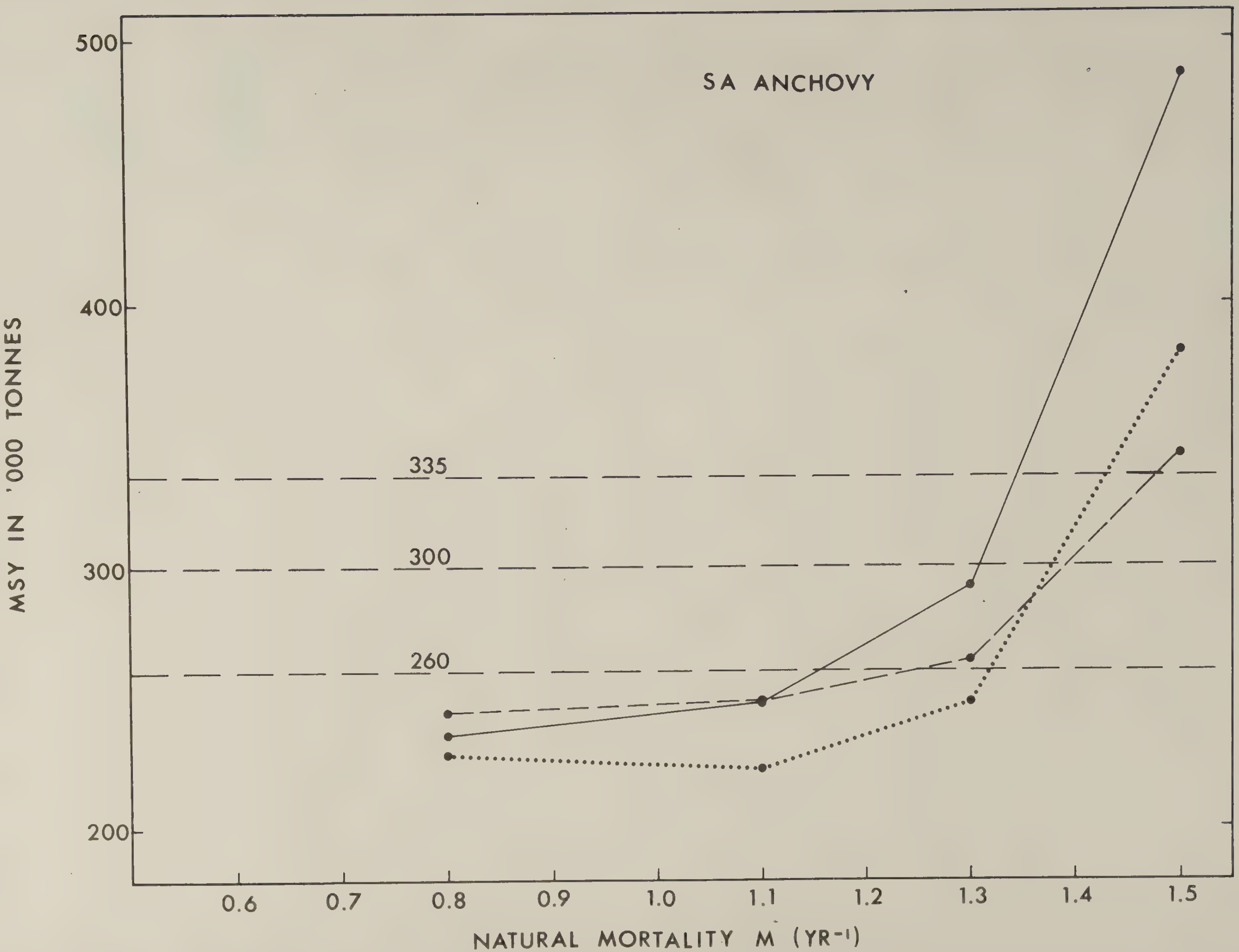

Fig. 22. Estimates of MSY as a function of natural mortality M for the SA anchovy. Conventions as for Fig. 21. Note evaluations have been carried out only at M=0.8, 1.1, 1.3, and 1.5; the adjoining straight lines are to guide the eye only.

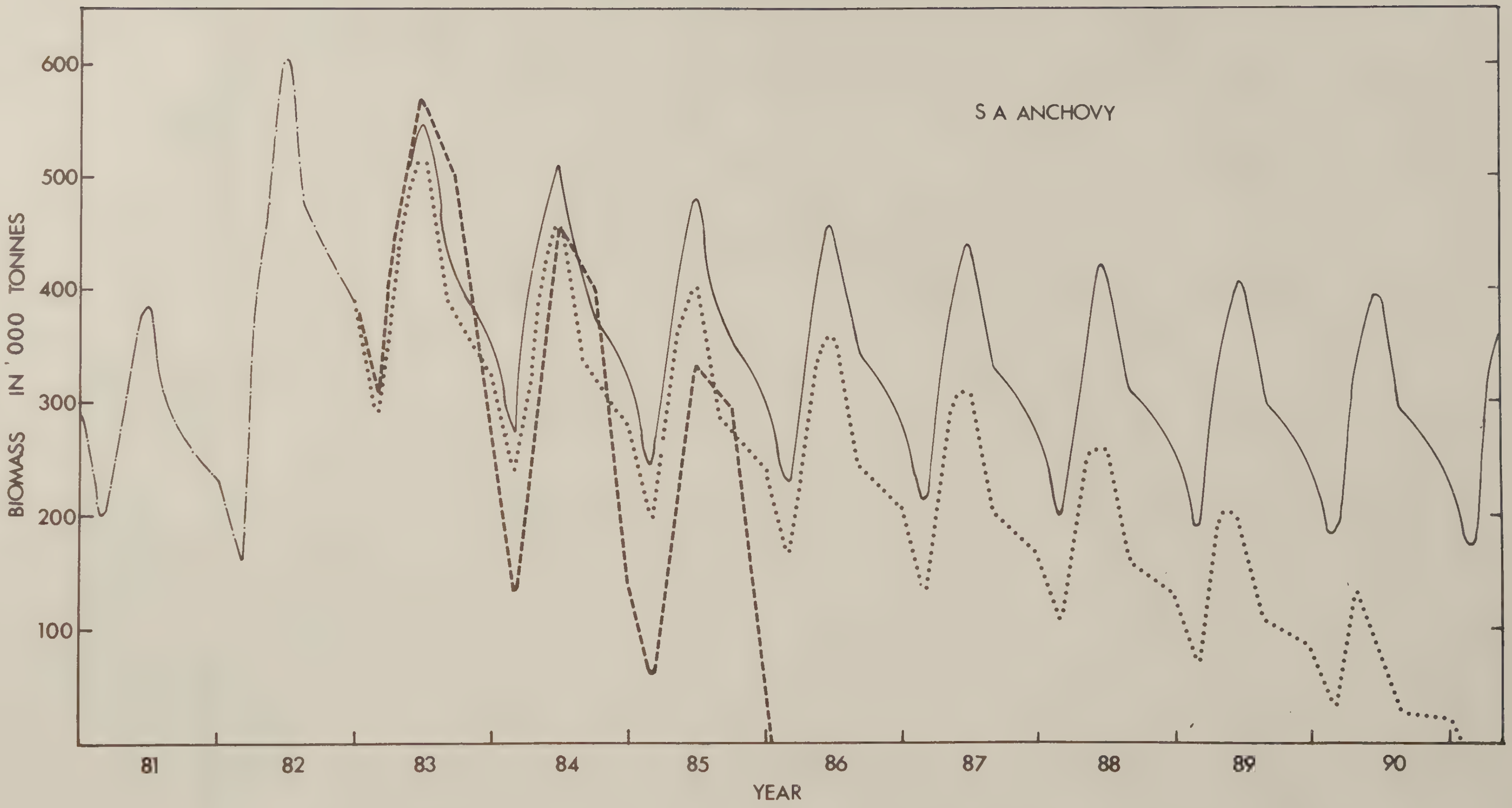

Fig. 23. Deterministic projections of the SA anchovy biomass from the calculated by VPA for 1982 (——) for various harvesting strategies. A Beverton-Holt fit to the stock-recruit curve has been used. All policies are constant annual quotas of 260 thousand tonnes (- - -) and 300 thousand tonnes (....)for the standard (January-August) season, and of 335 thousand tonnes (xxxx) for the new (mid-October-March) season, preceded by a 160 thousand tonne catch for the first half of 1983.

### b) Incorporating the effects of fluctuations

An MSY estimate alone is not sufficient basis for the management of a pelagic fishery. The production curves of Fig. 21 are only a representation of the situation "on average". Considerable residual variance is evident in the stock-recruit plots of Fig. 7 (see Table 7), and at any particular time more than the indicated sustainable yield can be taken if good recruitment (i.e. better than predicted by the stock-recruit plot) occurs and vice versa.

There may be little warning of downward stock fluctuations as if evident from the following examples:

(i) SWA/N pilchard recollapse: Table 8 (from Butterworth, 1980) shows the trends of various current biomass indices for this stock that were available or could have been calculated during the mid-1970's. Only by the beginning of 1978, with the collapse irreversible, were indices universally negative. The catch-statistics based indices show some negative features at the start of 1976, but by then an enormous quota reduction would have been required to counter the effects of both previous years' catches that had risen too high, and poor recruitment in 1975, which was to be followed by poorer recruitment still in 1976. Noticeable is the delayed response of CPUE to the decline, and the problem of increased modal length reflecting poor recruitment rather than a decline in fishing intensity.

Table 8: Summary of stock assessment indications for the SWA/N pilchard at various times compared to the actual stock situation.

| Beginning of year | | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|
| VPA | Catch-statistics based | +2 | 0 | -2 | -1 | -2 |
| CPUE | | +1 | +2 | -1 | 0 | -2 |
| Modal length | | 0 | +1 | 0 | +1 | -2 |
| Aerial | Direct | +1 | - | - | -2 | - |
| Egg | | +2 | - | - | - | - |
| Year-class strength compared to average | 1975 | - | (0) | -1 | 0 | -2 |
| | 1976 | - | - | (0) | -2 | -2 |
| Actual biomass | | 0 | -1 | -2 | -2 | -2 |
| Historic quota decision (Compared to previous season) | pre-season | +20% | +0% | +0% | -47% | -38% |
| | mid-season | | | -20% | -58% | -77% |
| Quota reduction required for 1,000,000-tonne 1979 biomass | | -42% | -61% | -78% | not possible | not possible |

The convention used, +2/+1/0/-1/-2, corresponds to strongly increasing/increasing/steady/decreasing/strongly decreasing.

(ii) SWA/N anchovy recruitment failure: Consider the trends evident prior to the 1982 season. Increasing CPUE is shown in Fig. 12d, and increasing egg production in Fig. 15b (VPA also showed an increase at that time, but through the current year F selection procedure, was primarily a reflection of the CPUE increase). In 1982 recruitment failed (Fig. 7d), and only 38% of a 220 thousand tonne quota was landed.

Some idea of the effects of fluctuations about the stock-recruitment plot is given in Fig. 24. The anchovy biomass is projected from that presently assessed for 1983 by VPA, for 20 and 100 year periods. For each future year the "environmental" parameter $\alpha$, which multiplies the recruitment predicted from the stock-recruit curve, is chosen at random from the set of $\alpha$ values assessed from VPA for the 1964-1982 period. The plots show the probability of "extinction" over projection periods under a constant quota policy; "extinction" is defined as the stock becoming too depleted to be capable of delivering the chosen fixed quota in a year.

It is noticeable that for the longer 100 year period, "extinction" occurs with certainty for quotas less than the deterministic MSY. The serial correlation in recruitment, which has yet to be taken into account in such simulation, would exacerbate this effect. This emphasizes the necessity for a strategy that reduces catches during periods of low biomass whether environmentally and/or fishery induced.

It is planned to use such simulation models to investigate more flexible harvesting strategies. For example, what is the maximum average yield that could be obtained at some acceptably small probability of stock "extinction", given exact knowledge of current biomass and the forthcoming season's recruitment, plus the Industry's preference that the quota not be amended by more than 15% (up or down) in any one year for logistic reasons (Anon., 1982). By taking better advantage of the extra yield available in years of good recruitment such average yield would be an improvement on the fixed quota for corresponding circumstances.

Such exact knowledge would never be obtainable. Example (i) above points to the problems with current biomass estimation, particularly the possible delayed response or decline underestimation of some methods. Further, for anchovy, the year's recruitment constitutes a major proportion of the catch so that a pre-fishing estimate is desirable.

Hydroacoustics surveys appear to offer the best prospects for both these measures. In principle it is preferable to census directly, rather than indirectly (e.g. egg surveys) where trends may be confounded by a changing relationship between the fish and the indicator being measured (perhaps due to density dependent effects).

However the accuracy with which such surveys can provide stock and recruitment values (whether relative or absolute) also requires evaluation. The larger the variance on these estimates, the less the difference between the comparable constant and variable quota prescriptions described above would become. One needs to know at what stage the extra costs of more intensive surveys to decrease variance, would exceed the benefits of improved resource utilisation achieved through more accurate information.

Although conceptually attractive, hydroacoustic surveys in Southern Africa need to show they can pass this test better than other indices of stock size and recruitment (also with their associated variances) that could be used. More significantly in practical terms, are results from such surveys going to be sufficient to convince decision makers?

The ultimate objective of research is an ability to predict the fluctuations ($\alpha$ values: Fig. 20) on the basis of environmental monitoring. If sufficient quantitative accuracy is obtainable this could in principle replace the far more expensive hydroacoustic surveys (which would provide the initial calibration). However, in this respect little success has been achieved thus far, though Boyd (1979) has reported a negative correlation of the SWA/N anchovy recruitment with temperature variability.

Economic factors also need to be taken into account in choosing an optimal harvesting strategy, but little work in this regard has been carried out to date. For example, a lesser tonnage of fish caught during a time of year when oil-yield is higher might be financially advantageous.

The comments above have been based entirely on a single species approach. Species interaction effects may well be significant, but will be difficult to model quantitatively. If adult food availability is indeed the primary limiting factor on the anchovy population, it will be difficult to believe that the presence of anchovy is not inhibiting possible pilchard recovery to some extent. Management recommendations may then have to take this into account. Albeit quantitatively in the first instance.

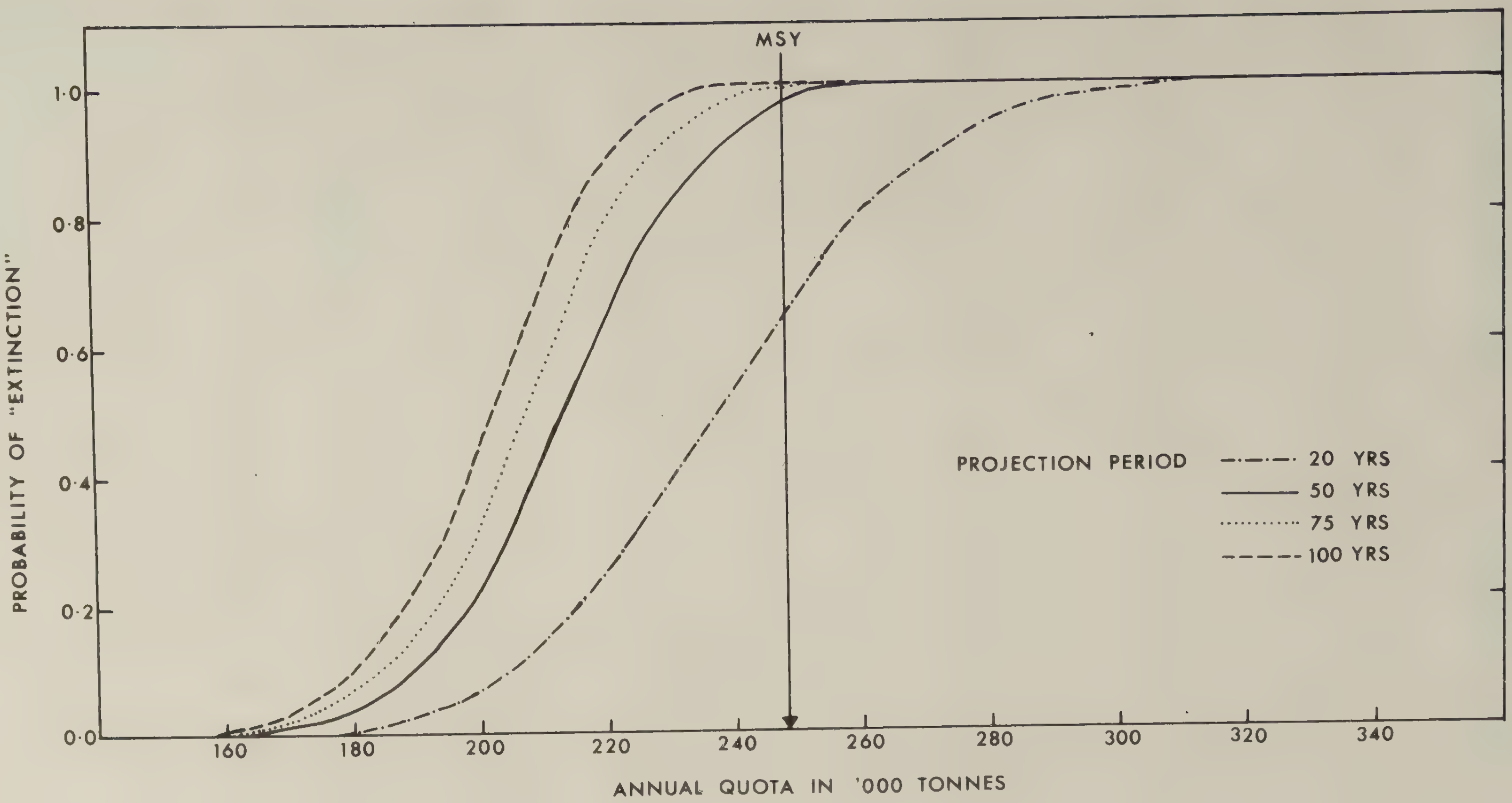

Fig. 24. Probability of "extinction" (see text) of the SA anchovy stock under standard season constant quota policies applied for 20 and 50 year periods from 1982. The projection commences with the VPA biomass and age structure of the population in 1982 and incorporates fluctuations about the deterministic Beverton-Holt fit to the stock-recruit relation (see text).

## Current management initiatives

The 1983 SWA/N pilchard quota has been set at 35 thousand tonnes to be taken with 28 mm nets from 13th March to 31st May, and constitutes a 5 thousand tonne increase compared to 1982. Pilchards caught after 31st May count towards an anchovy quota of 200 thousand tonnes (compared to 220 thousand tonnes in 1982) (Anon., 1983a).

Following recruitment failures in 1982, Thomas (1983) comments on pilchard: "any fishing on adults should therefore be banned in 1983, otherwise the stock will almost certainly be wiped out for good", while le Clus and Melo (1983) state in respect of anchovy that: "the initial quota should be very low and restraint...exercised".

The quota decisions, contrasting sharply with the statement of a recent Parliamentary Commission of Inquiry (Anon., 1980) that "the Commission wishes to reaffirm its belief that the exploitation level should be determined on scientific data only", can only be considered disappointing and unwise. A further disappointing feature is that the policy of a low initial quota for anchovy, which may be revised (probably raised) when results of the summer egg survey become available, has apparently been discarded; in principle although subsequent downward quota adjustment could be made should the survey results be poor, in reality this would be extremely difficult to achieve.

In SA, the scientific recommendation for a global quota reduction from 380 to 325 thousand tonnes for 1983 has again been rejected. Instead the Deputy Minister responsible has introduced an entirely new plan. The season that opened on 1st January will close on 30th June with a quota of 190 thousand tonnes applying to pilchard and anchovy only. Thereafter the season is to be changed to the summer months (15th October to 31st March) with a quota of 380 thousand tonnes for pilchard and anchovy only. The "split" quota is intended to encourage diversification of effort to other species.

The decision is apparently based on theories developed by Lochner (1980). Essentially Lochner's recommendations rest on three conclusions (derived by analogy from an electric circuit model): the peak spawning period for pelagic fish in October, pelagic fish spawn effectively only once, and pilchards and anchovy join commercially catchable shoals at ages of 1.35 years and 6 months respectively. On this basis fish caught during summer months have already effectively made their one and only contribution to future stocks and so may be removed without endangering the population. Various authors (1980) assert that the three conclusions indicated are all at variance with observational evidence.

A production curve corresponding to this summer fishing season is shown in Fig. 21. The resultant MSY is some 10% lower than for the standard January-August season: this occurs essentially because losses of juvenile anchovy to natural mortality over the winter months more than offset the gains in individual fish mass and spawning biomass by delaying exploitation. The deterministic projections shown in Fig. 23 correspond to a standard season 325 thousand tonne global quota (anchovy 260 thousand tonnes: past scientific recommendation), a standard season 380 thousand tonne global quota (anchovy 300 thousand tonnes: previous situation), and the new policy corresponding in due course to a 335 thousand tonne summer anchovy catch (i.e. assuming the relative species composition of the catch of the last few years remains unchanged). The projections indicate that though the lower anchovy catch for the first half of 1983 provides a temporary respite for the stock, this benefit is rapidly destroyed by the subsequent higher catch and lower sustainable yield available over the summer months.

The Deputy Minister concerned has recently announced that a scientific committee will be appointed to further consider the new proposals.

## ECONOMIC ASPECTS

The SA pelagic fishery has seen a major change in species composition; the SWA/N fishery has experienced both this and large fluctuations in total landings. How have the fishing companies been able to adapt to these changed circumstances?

Fig. 3 shows the trend in the number of vessels and the total fleet hold capacity operative in the two fisheries; the move to larger vessels is clear from the plots. In SA fleet hold capacity continued to rise in spite of the pilchard decline of the early 1960's; limitation was problematic to justify in the absence of estimates of the potential yield of the stocks. In any case a Boat Limitation Committee's advice was not accepted by the authorities on a number of occasions (Anon., 1971).

The only real decrease in SA hold capacity coincides with the 1975 decision to allocate specific quotas among the individual processors, removing the incentive for the individual to have maximal effort available to grab the largest possible slice of the global quota in a free-for-all situation.

Nevertheless the decrease in hold capacity following this was only some 15%, with considerable surplus effort still available. The reasons for this are probably psychological: first, the additional cost of maintaining the surplus effort already available is relatively low, and secondly the processor wants to avoid the embarassment of failing to achieve his quota in years of poor availability, while maintaining pressure for increased quotas (knowing that effort is available to achieve such increased quotas should they be granted).

Fig. 25 shows trends in meal, oil and canned fish production from the fishery. The major features are the peak in oil production corresponding to the peak pilchard catches of the early 1960's, and the fall-off in canning production with the pilchard (and horse mackerel) collapses. Mean production was relatively unaffected over this period.

Many of the companies operative in SA were also active in the SWA/N fishery, and it seems probable that the losses involved, particularly in the decline in the profitable canning production in SA, were offset by moving vessels and plant machinery during the mid-1960's to Walvis Bay where pilchard catches were increasing. Plots of number of vessels in Fig. 3 are not entirely consistent with this hypothesis, but may be confounded by vessles operating in both fisheries in the same year.

Pilchard canning production in SWA/N is indicated in Fig. 26. Though landings declined substantially from 1968 to 1971, only in 1971 was there any noticeable drop in the trend of increased canning production. Fig. 3b also indicates the initial pilchard collapse served only as a temporary brake on the increase of hold capacity. (Unlike SA, individual quotas were allocated to processors in SWA/N from the start of the fishery.)

With canned pilchard the industry's most profitable product, one may surmise that the impact on the industry of the initial pilchard collapse was by no means as severe as the actual decline in landings.

Aided by increasing efficiency, pilchard canning reached record levels in 1975, but by 1978 had dropped by 90% to cause the industry severe problems. With this second pilchard collapse came, eventually, a reaction to the surplus effort in the fleet (Fig. 3b)

The impact on the companies has probably been reduced by a number of factors. Towards the end of the 1970's many invested in fishing operations in Chile (including transfer of machinery) (Anon., 1981a, Anon., 1981b); a canning plant was opened recently at Gansbaai (SA) with machinery from SWA/N. Usage of meal plants and canneries was rationalised. As only RSW vessels (owned by the factories) were permitted to catch pilchard, private boat owners who contract to the companies suffered more in proportion. In a period of high interest rates, large cash holdings proved a profitable alternative investment.

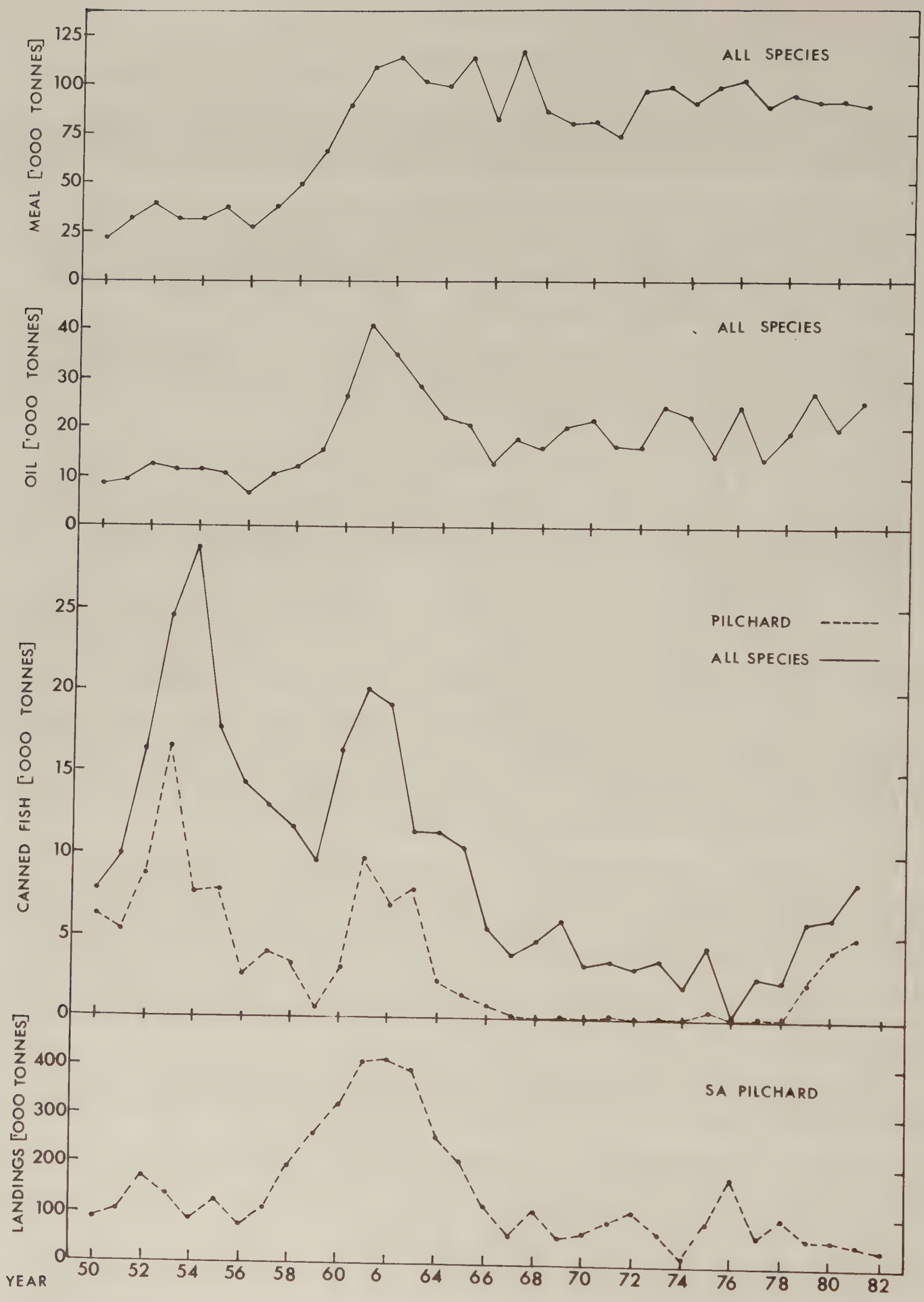

Fig. 25. Annual production of fish meal, oil and canned products from the SA pelagic fishery 1950-1981. Pilchard landings over this period are shown for comparison of trends.

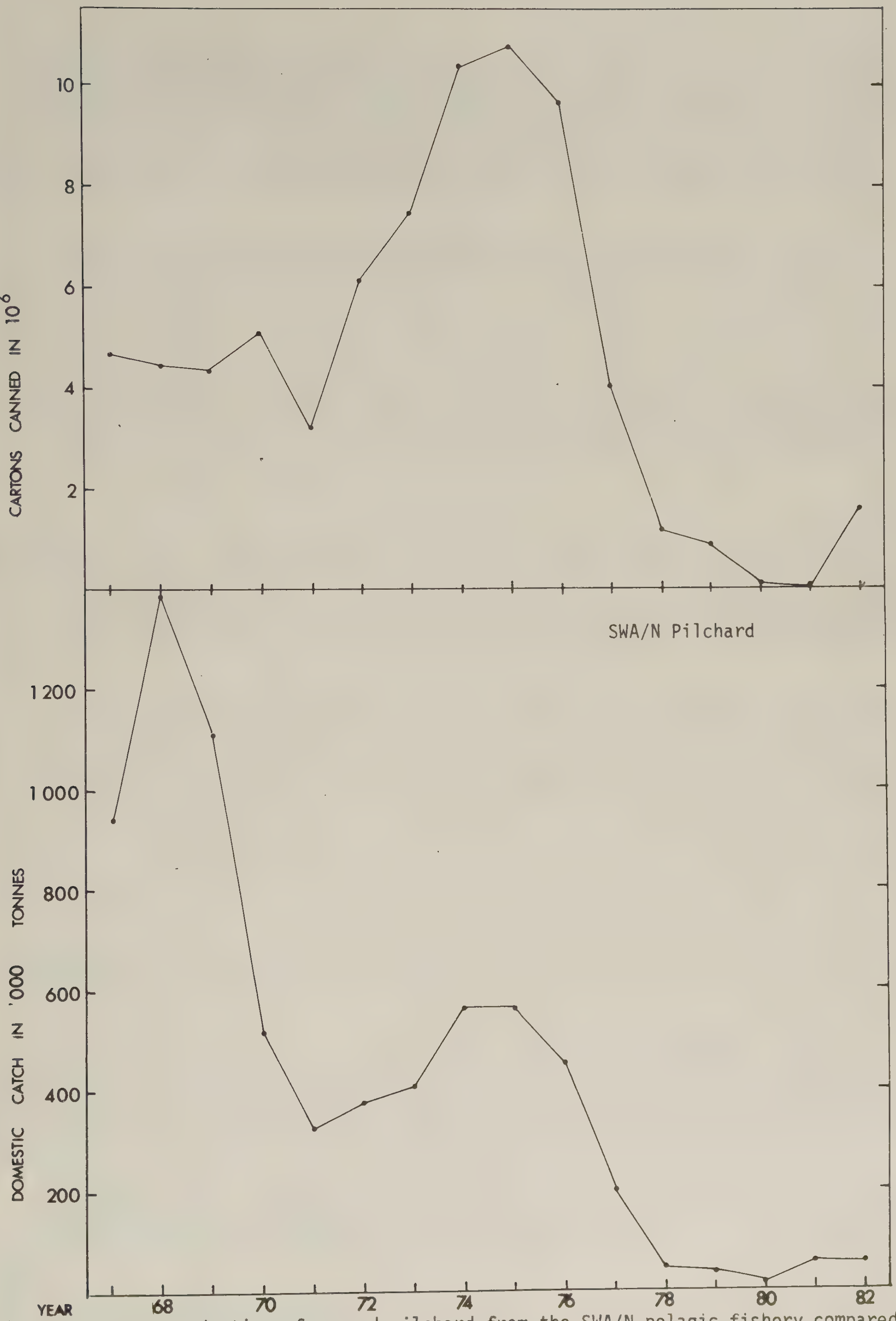

Fig. 26. Annual production of canned pilchard from the SWA/N pelagic fishery compared to domestic landings of pilchard. The canning trend should be considered as indicative rather than precise, as the "carton" unit varies dependent on the type of can, but is roughly equivalent to 10 kg of fish. (Data: Anon., 1983c)

Nevertheless, squeezed between rising costs (principally fuel), and the long term fall in the real price of fish meal on the domestic market through price control, the SWA/N industry incurred a cash loss on meal production in 1982, and also a net negative energy yield (fish oil vs fuel) (Bross, pers. comm.).

These circumstances must lead to unhealthy pressure for continued pilchard quotas to maintain canning from an increasingly fragile stock.

## MAJOR LESSONS OF THE SOUTHERN AFRICAN PELAGIC FISHERIES

### Ageing

Ageing is a cornerstone in fisheries assessments: to correctly determine stock trends, to calculate sustainable yields, and to identify years of good and bad recruitment. Regular and accurate ageing of samples from landings is essential. Density dependent responses and spatial differences in growth rates may well mask actual stock trends if length distributions alone are considered.

### Survey

Survey assessment methods are essential in spite of their higher costs. The accurate assessment of the current biomass level is most important for pelagic stocks, in particular for the timely detection of declines to allow the opportunity for adequate remedial management response. With anchovy landings heavily dependent on the current year's recruitment, early recruitment indices are also required, and hydroacoustic surveys appear the best method to obtain these.

Indications based on catch statistics have shown delayed response to stock declines, and need to be supplemented by other methods independent of the possible biases of samples from the fishery. Further, if malpractices are taking place, the Fishing Industry is aware that assessments from catch statistics are based on erroneous data; in such circumstances the trends produced by assessments may still have validity, although Industry representatives, aware of the questionable nature of the data, feel justified in opposing scientific recommendations. Consequently the results of independent survey enjoy greater respect.

### Regulation

Regulations must be enforcible, and should therefore be kept simple. Restrictions based on effort limitation alone would be inadequate: effort is difficult to define, and seems poorly related to fishing mortality F. Effort limitation may however have a role to play in eliminating the potential for malpractices.

Individually allocated quotas appear the best solution, and seem to be able to limit overcapitalisation to a certain extent. Although individual species quotas are biologically desirable, they could encourage malpractices such as dumping and species misidentification. Global quotas therefore seem more realistic measures.

The protection of the more heavily depleted species can be assisted by temporary closure of certain areas. This measure is more easily enforcible in SWA/N where all vessels operate from a single harbour; all vessels are thus equally disadvantaged and more readily policed. In SA, with 6 widely spread harbours, the situation is more problematic.

The actual benefit the stocks derive from the "day-to-day" monitoring and regulation of the fishery that such a scheme implies may not be substantial. Nevertheless there is the psychological advantage of positive reaction of the Fishing Industry to research being seen to be done. Although many fishermen prefer to believe that the fish have temporarily "gone somewhere else" rather than that fishing has depleted the stock, they do appreciate the undesirability of catching fish that are too small (the yield per recruit concept), and respond more positively to restrictions on this score.

## The Decision Making Process

The history of the Southern African pelagic fisheries shows quite clearly that conservation measures have been adopted only once evidence of stock depletion had become overwhelming. Regarding SWA/N, Troadec et al. (1980) comment that this delayed action tended to amplify the natural fluctuations in stock size, and increased the risk of collapse.

Cram (1981) argues that had the SWA/N aerial surveys continued in 1975 and 1976, earlier detection of the pilchard stock decline would have occurred, and consequently quotas could have been reduced at an earlier date. The first of his conclusions is more readily accepted than the second. The Fishing Industry acceeded to proposed quota increases while surveys indicated stock increments; one suspects they might have been somewhat more reluctant in the reverse situation.

The Industry intuitively bases its appraisals of the situation on the index to which it is sensitive, i.e. catch rate; problems occur because CPUE is not a reliable indicator. In particular, larger selectivities for older fish, or increase in catchability q as biomass declines, means that CPUE may lag or underestimate stock declines; there is some evidence that both these effects have occurred in Southern African fisheries.

Accordingly, given the heavy representation of the Fishing Industry on the Fisheries Advisory Councils, the delay in management reaction is not surprising. Anon. (1980) notes "In the past, higher quotas than those recommended by the Director of Sea Fisheries were often granted".

In these circumstances scientists have been forced to play a protectionist role, and, under-represented on such advisory bodies, they have been able only to delay rather than prevent the over-exploitation of a number of resources.

The great need is for a counter-weight to overoptimistic industrial pressure in the decision making process. Given such a lobby, resource evaluation scientists could revert to their proper role as indifferent advisers for rational long-term resource utilization. In this way such scientists would be seen as holding a central rather than an extreme viewpoint in the process of compromise the politician in ultimate authority has to achieve.

What group can provide such a counter-weight role? The conservationist lobby is one possibility. A recent Parliamentary Commission of Inquiry appears to have thought along these lines in recommending replacement of the Fisheries Advisory Council by a body including three representatives from conservation organisations (Anon., 1980). This led to the Advisory Council's composition being amended to include more scientific representatives and the Director of Nature Conservation in the Cape, though representatives associated with Fishing Industry remain in the majority. It is too early to judge whether this change is having any impact.

Another possible contender for the counter-weight role is the media. Press comment on the difference between the SA global quota allocation of 380 thousand tonnes and scientific recommendations of 325 thousand tonnes (Ferreira, 1982), led to the then responsible Minister having to explain his decision in response to questions from the Opposition during the Parliamentary session (Anon., 1982a). There may well be valid reasons that justify exceeding quotas scientifically recommended in the short term, but it is important in these situations that such decisions are clearly rationalised.

The concept of the scientific viewpoint appearing as an equilibrium of industry and conservationist extremes is appealing. Equilibria however are not necessarily stable. The current situation in the International Whaling Commission could be argued as an example of such instability, though "ethical" considerations are of greater significance there.

Scientists also need to critically review their own record, to evaluate why their management impact has not been greater. The business of fisheries scientists (in a management context) is quantitative prediction, but the development of such methods in Southern Africa has been slow (the first estimates of sustainable yields appeared only in the 1970's).

Qualitative advice recommending "caution" without associated quantification is inadequate. When a resource eventually experiences problems in such circumstances, there is little real justification in claiming an inevitable certainty as a prediction fulfilled because advice was not heeded.

The nature of fisheries assessment is such that the best predictions possible may prove inaccurate (perhaps substantially so); but that is neither a reason to avoid making them, nor necessarily one for censure after the event. To adopt an approach so cautious that things cannot possibly go wrong is to waste the resource, and is an attitude the Fishing Industry has some justification in opposing.

The scientist's classical training emphasises that conclusions must be backed by a full discussion and justification (as far as possible) of the assumptions from which they were derived. This is not necessarily the best way to present arguments to decision makers who have no scientific training, as such presentations can give the impression of inconclusiveness.

Having judged the appropriateness of the alternative sets of assumptions they need to produce a "best" estimate or prediction (albeit one not fully justified in the strict scientific sense), scientists should then present precise recommendations to higher authority.[2] Unfortunately however, scientists sometimes avoid such judgements, effectively abrogating their responsibilities to such authorities who are less well placed to make the evaluation.

Fisheries science in Southern Africa needs to focus further on quantitative prediction (albeit prediction in a probabilistic sense) if it is to influence and benefit the Fishing Industry more effectively.

A first step (MacCall in Anon., 1982) in the pelagic area should be the development of an explicit predetermined contingency plan for years of poor anchovy recruitment.

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[2] These should take the form of the range of harvesting options and associated quantitative consequences for the stock, that the chosen model produces. The choice between such options goes beyond the purely scientific domain.

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*SOUTH EAST ATLANTIC - ATLANTICO SUDORIENTAL*

# ASPECTS OF VARIABILITY OF SOME NERITIC STOCKS IN THE SOUTHERN BENGUELA SYSTEM

by

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## Resumen

El sistema de afloramientos del sur de Benguela soporta una gran pesquería comercial que opera con redes de cerco, arrastre de media agua y de fondo. Entre las especies que forman cardúmenes están: *Sardinops ocellata*, *Engraulis cepensis*, *Trachurus trachurus*, *Scomber japonicus* y *Etrumeus teres*, mientras que las principales especies que contribuyen a las pesquerías de media agua y de fondo son *T. trachurus* y *Merluccius spp* respectivamente. Frente al Cabo Oeste de la República de Sudáfrica y frentè a la parte Sudoeste de Africa los desembarques de los cerqueros estaban inicialmente dominados por *Sardinops*, pero después del colapso de la población de *Sardinops* y el cambio del tamaño de malla de las redes, la especie que contribuye mayormente a las capturas en las dos regiones es *Engraulis*. Frente al Cabo del Oeste las capturas de *Trachurus* y *Scomber* con redes de cerco eran abundantes en el pasado, pero ahora son insignificantes. Las capturas en media agua de *Trachurus* frente al sur oeste de Africa han aumentado marcadamente en años recientes. Arrastreros de fondo capturaron más de un millón de toneladas de *Merluccius* en el Atlántico Sudeste en 1973.

Hubo un amplio aumento del reclutamiento en cada una de las once poblaciones estudiadas. En ocho de las poblaciones examinadas el reclutamiento puede ser descrito como eruptivo, con la fuerza de las clases anuales que aumentan por lo menos durante dos generaciones pero que luego declinan marcadamente. No se observaron períodos de corta duración donde las fallas del reclutamiento hayan tenido una magnitud comparable a la de los períodos eruptivos, pero en algunos casos el reclutamiento disminuyó y se mantuvo a un nivel bastante bajo. En algunas ocasiones, algunas poblaciones de peces experimentaron simultaneamente reclutamientos favorables, cuando se observaba el mayor incremento relativo del reclutamiento en la especie más abundante.

Algunos de los grandes aumentos de reclutamiento no pudieron ser conectados con ningún fenómeno ambiental obvio, pero aparentemente otros pueden ser relacionados con factores ambientales. Las mayores perturbaciones en las poblaciones de peces pelágicos parecen haber ocurrido antes que se iniciara la pesca comercial con redes de cerco. La estabilización de la cosecha de guano en las islas Guaneras frente a Sudáfrica en los primeros años de la explotación de peces pelágicos con redes de cerco sugiere que los predatores (i.e. aves guaneras) y la pesca comercial compiten por la producción excedente proveniente de la erupción del reclutamiento. Por otro lado la amplia disminución de la cosecha de guano que siguió el colapso del stock de *Sardinops*, sugiere que las fluctuaciones significativas en el tamaño de las poblaciones principales se reflejan en la biomasa de la combinación de especies en la región. Los colapsos de las poblaciones de *Sardinops* frente a Sudáfrica y el Sudoeste de Africa fueron seguidos en ambos casos de un crecimiento del tipo logístico de otras especies. La distribución geográfica de algunas especies puede estar relacionada con el tamaño de la población, y la región sur de Benguela parece contener dos subsistemas. Los principales cambios en la abundancia relativa de las especies se reflejó en la dieta de predatores. Un aumento de la mortalidad natural puede demorar el reemplazo de una especie por otra. La explotación intensiva de peces pelágicos ha dado por resultado en una dominancia de especies de vida corta.

# INTRODUCTION

The southern Benguela region is a highly productive upwelling area supporting large commercial fisheries (Stander, 1964; Shannon, 1966; Dram, 1977; Newman, 1977; Crawford et al., 1980; Shannon and Anderson, 1982).

Multispecies pelagic fisheries operate off the Republic of South Africa's Western Cape and off Southwest Africa (Cram, 1977; Troadec et al., 1980; Newman and Crawford, 1980). Species contributing to the catches are similar in both regions and include pilchards *Sardinops ocellata*, horsemackerel *Trachurus trachurus*, anchovies *Engraulis capensis*, chubmackerel *Scomber japonicus*, roundherring *Etrumeus teres* and a myctophid *Lampanyctodes hectoris*. The bearded goby *Sufflogobius bibarbatus* has been caught off Namibia, S.W. Africa.

Stock separation has yet to be satisfactorily resolved (Butterworth, this consultation), but assessments have tended to regard the two regions (Fig. 1) as separate entities. Catches of *Sardinops* off the Western Cape declined after 1962, whereas those off South West Africa remained at a high level until 1968 (Tables 1 and 2). Results of a tagging experiment indicated that *Sardinpos* moved freely between Walvis Bay and Lüderitz off Namibia, South West Africa, but that the fishery of the Western Cape exploited a different stock (Newman, 1970b). On the basis of discrepancies in catch rates (de Villiers, 1977) backed up by biological evidence (Draganik, 1977), the International Commission for the Southeast

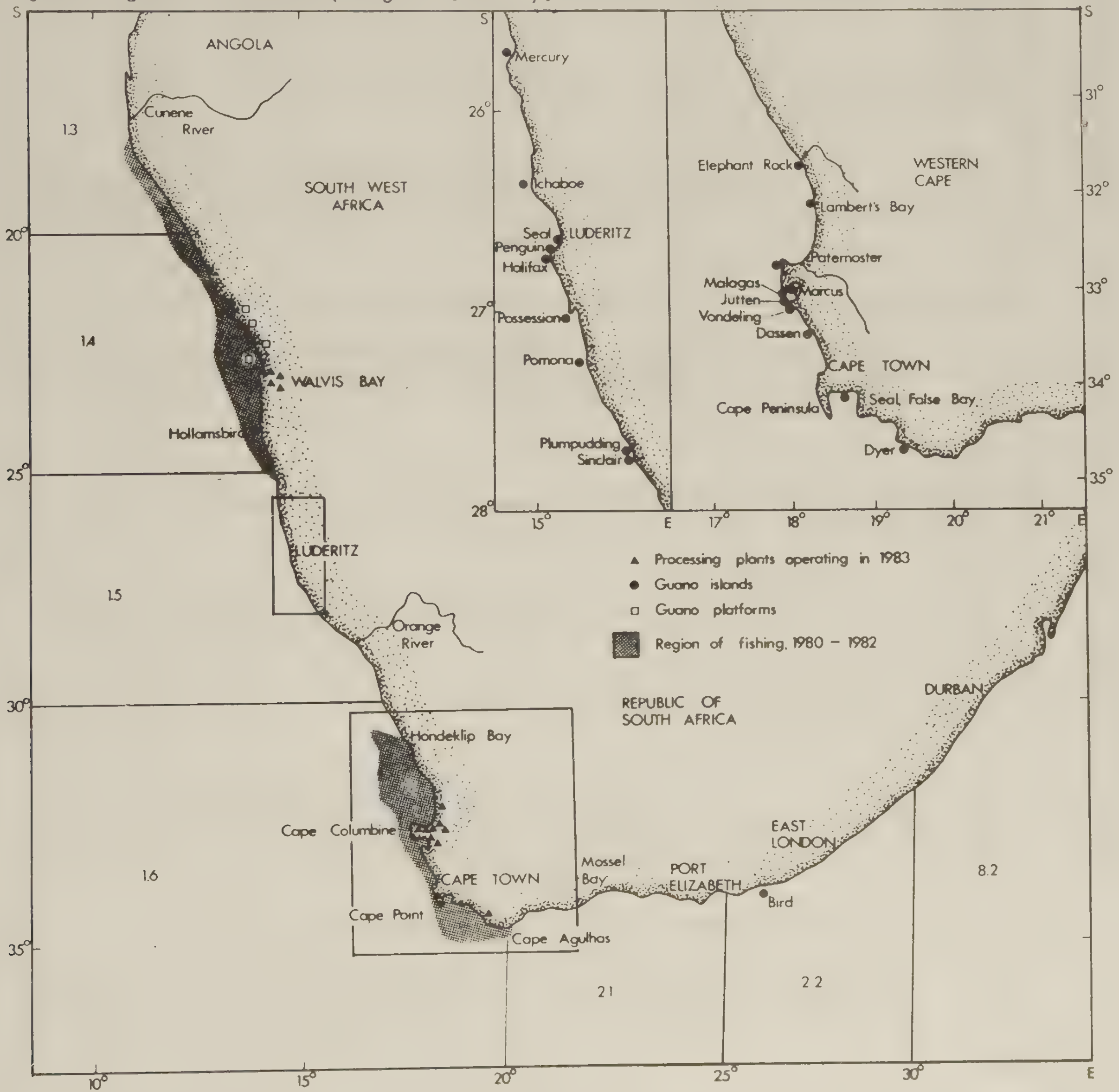
ANGOLA
Cunene River
SOUTH WEST AFRICA
1.3
1.4
1.5
1.6
WALVIS BAY
Hollamsbird
LÜDERITZ
Orange River
REPUBLIC OF SOUTH AFRICA
Hondeklip Bay
Cape Columbine
CAPE TOWN
Cape Point
Cape Agulhas
Mossel Bay
PORT ELIZABETH
Bird
EAST LONDON
DURBAN
2.1
2.2
8.2
Mercury
Ichaboe
Seal
LUDERITZ
Penguin
Halifax
Possession
Pomona
Plumpudding
Sinclair
Elephant Rock
WESTERN CAPE
Lambert's Bay
Paternoster
Malagas
Marcus
Jutten
Vondeling
Dassen
CAPE TOWN
Cape Peninsula
Seal
False Bay
Dyer
▲ Processing plants operating in 1983
● Guano islands
□ Guano platforms
▨ Region of fishing, 1980 – 1982
S
20°
25°
30°
35°
26°
27°
28°
31°
32°
33°
34°
35°
10°
15°
20°
25°
30°
17°
18°
19°
21°
E

Fig. 1. Map of southern Africa illustrating regions of purse seine fishing. ICSEAF subdivisions, and locations of plants operative in 1983 for the processing of pelagic fishes and of guano islands and platforms.

TABLE 1: Species composition of South African purse seine landings ('000 t), 1950-1982.

| Year | Sardinops | Engraulis | Trachurus | Scomber | Etrumeus | Lampanyctodes | Total |
|---|---|---|---|---|---|---|---|
| 1950 | 85,3 | - | 49,9 | - | - | - | 135,2 |
| 1951 | 101,9 | - | 98,5 | - | - | - | 200,4 |
| 1952 | 170,0 | - | 102,6 | - | - | - | 272,6 |
| 1953 | 132,5 | - | 85,2 | - | - | - | 217,7 |
| 1954 | 88,3 | - | 118,1 | 4,0 | - | - | 210,5 |
| 1955 | 121,9 | - | 78,8 | 20,2 | - | - | 221,0 |
| 1956 | 76,6 | - | 45,8 | 32,6 | - | - | 154,9 |
| 1957 | 109,5 | - | 84,6 | 7,4 | - | - | 201,5 |
| 1958 | 194,4 | 0,2 | 56,4 | 21,6 | 0,8 | - | 273,4 |
| 1959 | 260,2 | 1,4 | 17,7 | 33,1 | 2,6 | - | 314,9 |
| 1960 | 318,0 | - | 62,9 | 31,0 | 0,1 | - | 412,0 |
| 1961 | 402,2 | - | 38,9 | 49,7 | 0,1 | - | 490,9 |
| 1962 | 410,2 | - | 66,7 | 20,4 | 0,1 | - | 497,3 |
| 1963 | 390,1 | 0,3 | 23,2 | 13,2 | 0,2 | - | 427,0 |
| 1964 | 256,1 | 92,4 | 24,4 | 50,0 | 2,7 | - | 425,6 |
| 1965 | 204,5 | 171,0 | 55,0 | 41,4 | 8,2 | - | 480,1 |
| 1966 | 118,0 | 143,9 | 26,3 | 53,4 | 15,4 | - | 357,1 |
| 1967 | 69,7 | 270,6 | 8,8 | 128,2 | 32,0 | - | 509,3 |
| 1968 | 107,8 | 138,1 | 1,4 | 91,0 | 30,3 | 0,1 | 368,6 |
| 1969 | 56,1 | 149,2 | 26,8 | 91,7 | 23,3 | 4,9 | 352,0 |
| 1970 | 61,8 | 169,3 | 7,9 | 77,9 | 23,7 | 18,2 | 356,0 |
| 1971 | 87,6 | 157,3 | 2,2 | 54,2 | 21,6 | 2,0 | 324,9 |
| 1972 | 104,2 | 235,6 | 1,3 | 56,7 | 20,6 | 15,2 | 433,6 |
| 1973 | 69,0 | 250,9 | 1,6 | 58,8 | 28,7 | 42,4 | 451,4 |
| 1974 | 16,0 | 349,8 | 2,5 | 30,7 | 1,3 | 0,3 | 400,5 |
| 1975 | 39,2 | 223,6 | 1,6 | 69,3 | 23,6 | 0,1 | 407,4 |
| 1976 | 176,4 | 218,3 | 0,4 | 0,5 | 11,7 | 0,1 | 407,5 |
| 1977 | 57,8 | 235,5 | 1,9 | 21,3 | 35,0 | 5,6 | 357,2 |
| 1978 | 97,0 | 209,5 | 3,6 | 2,4 | 67,0 | 1,0 | 380,4 |
| 1979 | 52,9 | 291,4 | 4,3 | 2,7 | 21,0 | 8,7 | 380,9 |
| 1980 | 50,4 | 315,5 | 0,4 | 0,2 | 14,1 | 0,1 | 380,5 |
| 1981 | 46,2 | 292,0 | 6,1 | 0,3 | 24,3 | 10,3 | 379,2 |
| 1982 | 33,5 | 306,9 | 1,1 | 2,7 | 31,0 | 0,7 | 375,9 |

TABLE 2: Species composition of Nambian/S.W. African purseseine landings ('000 t), 1950-1982).

| Year | Sardinops | Trachurus | Engraulis | Other* | Total |
|---|---|---|---|---|---|
| 1950 | 46,7 | - | - | | 46,7 |
| 951 | 127,2 | - | - | | 127,2 |
| 1952 | 225,8 | - | - | | 225,8 |
| 1953 | 262,2 | - | - | | 262,2 |
| 1954 | 250,6 | - | - | | 250,6 |
| 1955 | 227,1 | - | - | | 227,1 |
| 1956 | 227,9 | - | - | | 227,9 |
| 1957 | 227,5 | - | - | | 227,5 |
| 1958 | 229,1 | - | - | | 229,1 |
| 1959 | 273,5 | - | - | | 273,5 |
| 1960 | 283,3 | - | - | | 283,3 |
| 1961 | 343,5 | - | - | | 343,5 |
| 1962 | 379,4 | - | - | | 397,4 |
| 1963 | 555,2 | - | - | | 555,2 |
| 1964 | 635,9 | - | 0,6 | | 636,5 |
| 1965 | 666,1 | - | 1,0 | | 667,1 |
| 1966 | 718,5 | - | 3,3 | | 721,8 |
| 1967 | 926,0 | - | 24,3 | | 950,3 |
| 1968 | 1 386,6 | - | 161,2 | | 1 547,8 |
| 1969 | 1 111,0 | - | 226,1 | | 1 337,1 |
| 1970 | 513,7 | - | 188,9 | | 702,6 |
| 1971 | 325,1 | 140,2 | 184,7 | 5,2 | 655,2 |
| 1972 | 373,5 | 21,7 | 136,6 | 2,4 | 534,2 |
| 1973 | 408,1 | 12,4 | 296,1 | 4,2 | 720,8 |
| 1974 | 561,6 | 30,1 | 249,1 | 2,1 | 842,9 |
| 1975 | 561,4 | 14,1 | 186,4 | 7,7 | 769,6 |
| 1976 | 451,7 | 23,2 | 87,8 | 7,6 | 570,3 |
| 1977 | 200,0 | 81,9 | 132,9 | 1,0 | 415,8 |
| 1978 | 46,0 | 9,0 | 355,4 | 0,1 | 410,5 |
| 1979 | 33,8 | 27,9 | 277,5 | 1,6 | 340,8 |
| 1980 | 10,8 | 39,2 | 190,2 | 0,2 | 240,3 |
| 1981 | 52,4 | 4,0 | 199,1 | 0,6 | 255,5 |

* Includes Scomber, Etrumeus, Lampanyctodes, Sufflogobius and Sxyphozoa.

Atlantic Fisheries (ICSEAF) recognises three separate stocks of *Trachurus*: one in ICSEAF Divisions 1.3 and 1.4, a second in Divisions 1.5 and 1.6, and a third in Divisions 2.1 and 2.2 (Crawford, 1981c). Badenhorst and Boyd (1980) have speculated that anchovies spawned off the Western Cape are transported by currents to the Lüderitz vicinity and cite movements of a drogue and a satellite-tracked drifter (Harris and Shannon, 1979) in support of their hypothesis. However, preliminary results suggest that the South West African and Western Cape concentrations of anchovies may be genetically distinguishable (Armstrong et al., 1983).

Hakes *Merluccius* spp. are trawled demersally off both South and South West Africa (Tables 3 and 4). Stock identity is under review (Lleonart et al., 1983), but traditional assessments have recognised separate populations for ICSEAF Divisions 1.3 and 1.4, ICSEAF Division 1.5, ICSEAF Division 1.6 and ICSEAF Divisions 2.1 and 2.2 (e.g. Newman et al., 1976a; 1976b; 1976c).

In a preliminary discussion of aspects of variability of some neritic stocks in the Southeast Atlantic this paper accepts traditionally recognised stock separations, that is it regards pelagic populations contributing to the purseseine fishery off South West Africa as distinct from those harvested off the Western Cape. Similarly hakes trawled off South West Africa and off the Western Cape are regarded as contributing to different populations. Should future research reveal the situation to be otherwise, stock trends indicated by current assessments and hence the basis of this paper may prove invalid.

## THE ENVIRONMENT

The cool Benguela current flows north along the southern African west coast between latitudes 35°S and 15°S (Newman, 1977). To the east of Cape Point (Fig. 1) temperatures increase under the influence of the Agulhas Current (Shannon, 1966), whereas north of Walvis Bay the warm Angola current may intrude from the northwest (Stander, 1964; O'Toole, 1980; Badenhorst and Boyd, 1980). Total production of the Benguela upwelling system has been calculated as 375 x 10~6 tons C/y (Cushing, 1969). Production up to 1.5 g C/m~2/d has been measured in upwelling plumes (Nielsen and Jensen, 1957).

Along the South West African coast, mid-winter (July) marks the onset of upwelling. Upwelling attains a maximum in spring, is of little consequence in summer except towards the south, and is often absent during autumn (Stander, 1964). Intensity of upwelling is particularly high between the Orange River and Lüderitz and lessens substantially north of Walvis Bay (Stander, 1964). Between latitudes 22°S and 19°S there are frequently onshore movements during spring and summer of a surface water mass whose temperature and salinity characteristics suggest that it derives from mixing of the cold Benguela Current from the south with the warmer Angola Current from the north (O'Toole, 1980).

Off the Republic of South Africa's Western Cape upwelling is initiated in spring, is strong during summer, is moderate or absent in autumn and is at a minimum in winter (Shannon, 1966). The reason for the discrepancy in upwelling seasons off South West Africa and the Western Cape is that in the north southerly to southeasterly winds are strongest from August through October, whereas in the south winds blowing parallel to the coast are maximal in summer (Stander, 1964; Shannon, 1966). The Western Cape system is rapidly pulsed and can be divided into four quasi-independent upwelling regions: the Namaqua area near Hondeklip Bay where extensive phytoplankton blooms occur; the Cape Columbine region from where upwelling plumes may extend northwards for more than 200 km under the influence of the Benguela Current; the Cape Peninsula system where up to three discrete plumes may develop simultaneously; and the region between Cape Agulhas and Cape Point (Shannon and Anderson, 1982). The upwelling plumes are separated from oceanic waters by sharp gradients of temperature and salinity. Strong equatorward jet currents are often associated with these frontal systems (Bang and Andrews, 1974). East of Cape Agulhas limited upwelling takes place off prominent capes, especially during summer and autumn (Schumann et al., 1982).

TABLE 3: Catch, effort and South African catch per unit effort for hakes _Merluccius_ spp. in ICSEAF Division 1.6, 1964 - 1981.

| Year | Catch (t) | Effort (std trawler days) | South African c.p.u.e. (t/std trawler day) |
|---|---|---|---|
| 1964 | 162 300 | 11 116 | 14,60 |
| 1965 | 203 300 | 18 755 | 10,84 |
| 1966 | 195 000 | 18 344 | 10,63 |
| 1967 | 176 700 | 17 652 | 10,01 |
| 1968 | 143 600 | 14 346 | 10,01 |
| 1969 | 165 100 | 19 153 | 8,62 |
| 1970 | 142 500 | 19 710 | 7,23 |
| 1971 | 202 000 | 28 491 | 7,09 |
| 1972 | 243 900 | 49 776 | 4,90 |
| 1973 | 157 800 | 31 751 | 4,97 |
| 1974 | 123 000 | 26 452 | 4,65 |
| 1975 | 89 600 | 19 227 | 4,66 |
| 1976 | 143 400 | 26 804 | 5,35 |
| 1977 | 97 500 | 20 145 | 4,84 |
| 1978 | 101 700 | 17 237 | 5,90 |
| 1979 | 90 400 | 14 747 | 6,13 |
| 1980 | 101 500 | 18 522 | 5,48 |
| 1981 | 99 600 | 17 148 | 5,81 |

TABLE 4: Annual catches ('000 t) of horsemackerel and hakes in the Namibian/S.W. African region, 1965-1981

| Year | _Trachurus_ | _Merluccius_ ICSEAF Divisions 1.3 & 1.4 | _Merluccius_ ICSEAF Division 1.5 |
|---|---|---|---|
| Source | Babayan _et al_ (1983) | Terre (1983) | Anon (1983) |
| 1965 | - | 93,5 | 99,7 |
| 1966 | 99,6 | 212,4 | 122,2 |
| 1967 | 72,4 | 195,0 | 199,4 |
| 1968 | 69,2 | 382,7 | 247,7 |
| 1969 | 46,5 | 320,5 | 206,2 |
| 1970 | 50,4 | 402,5 | 224,7 |
| 1971 | 214,5 | 365,6 | 229,7 |
| 1972 | 72,2 | 606,1 | 214,0 |
| 1973 | 271,4 | 377,6 | 290,3 |
| 1974 | 193,1 | 318,8 | 195,7 |
| 1975 | 242,2 | 309,4 | 178,7 |
| 1976 | 456,2 | 369,8 | 209,7 |
| 1977 | 352,1 | 277,5 | 157,7 |
| 1978 | 516,2 | 258,1 | 124,2 |
| 1979 | 401,6 | 172,3 | 130,0 |
| 1980 | 544,1 | 90,5 | 70,1 |
| 1981 | 590,5 | 100,0* | 116,4 |

*Estimated

## DISTRIBUTIONAL ECOLOGY OF THE FISH POPULATIONS

Seasonal patterns of distribution for contributors to the Western Cape purseseine fishery have been summarized by Crawford (1980a). Adult anchovies and pilchards aged between two and four tend to spawn in warm water found east of Cape Point (Figs. 2 and 3). The cool upwelled water of the west coast is avoided. Lower lethal temperature limits for eggs of pilchards and anchovies are 13.0°C and 14.0°C respectively, their rates of development increasing with temperature (King, 1977a; King et al., 1978).

Five- and six-age group pilchards used to spawn off St. Helena Bay in warm water outside the oceanic front, but heavy exploitation of juveniles means that few fish currently attain these ages (Crawford et al., 1978).

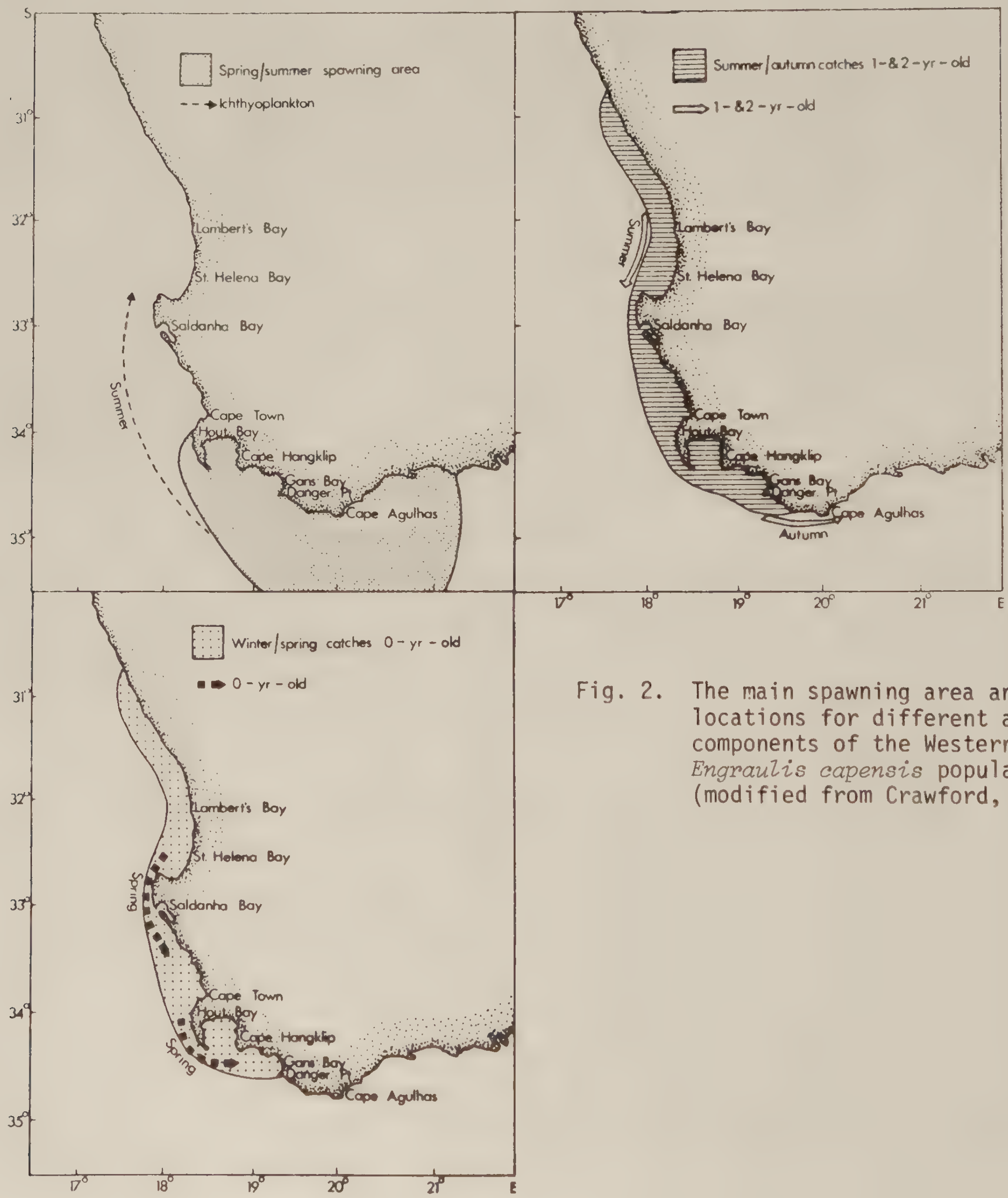
S
Spring/summer spawning area
Ichthyoplankton
Summer
Lambert's Bay
St. Helena Bay
Saldanha Bay
Cape Town
Hout Bay
Cape Hangklip
Gans Bay
Danger Pt
Cape Agulhas
Summer/autumn catches 1- & 2-yr-old
1- & 2-yr-old
Autumn
Winter/spring catches 0-yr-old
0-yr-old
Spring
31°
32°
33°
34°
35°
17°
18°
19°
20°
21°
E

Fig. 2. The main spawning area and catch locations for different age components of the Western Cape *Engraulis capensis* population (modified from Crawford, 1980a).

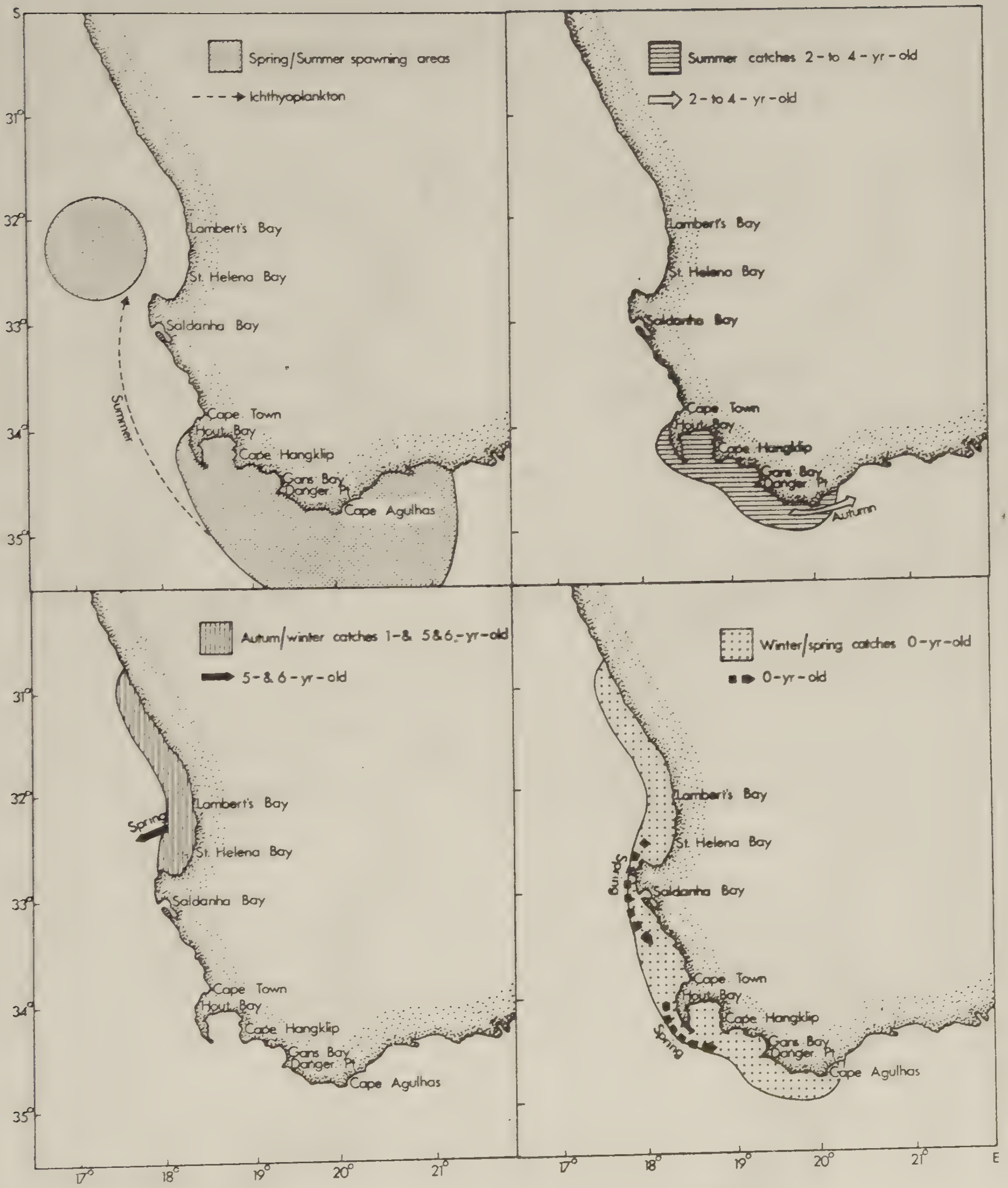
Spring/Summer spawning areas
Ichthyoplankton
Summer
Summer catches 2- to 4-yr-old
2- to 4-yr-old
Autumn
Autum/winter catches 1-& 5&6-yr-old
5-& 6-yr-old
Spring
Winter/spring catches 0-yr-old
0-yr-old
Spring
Spring
Lambert's Bay
St. Helena Bay
Saldanha Bay
Cape Town
Hout Bay
Cape Hangklip
Gans Bay
Danger Pt
Cape Agulhas
S
31°
32°
33°
34°
35°
17°
18°
19°
20°
21°
E

Fig. 3. The main spawning areas and catch locations for different age components of the Western Cape *Sardinops ocellata* population (modified from Crawford, 1980a).

Horsemackerel and roundherring also spawn along the west coast outside the oceanic front, although spawning grounds of the latter include areas that are subject to invasion by cold upwelling plumes (Figs. 4 and 5). Eggs of these species again develop more rapidly in warmer water, but can tolerate temperatures at least as low as 12.6$^{0}$C (horsemackerel) and 11.0$^{0}$C (roundherring) according to King et al. (1977) and O'Toole and King (1974). The spawning season for anchovies, pilchards and horsemackerel is spring and summer, whereas that for roundherring is from late winter through early summer (Davies et al., 1981).

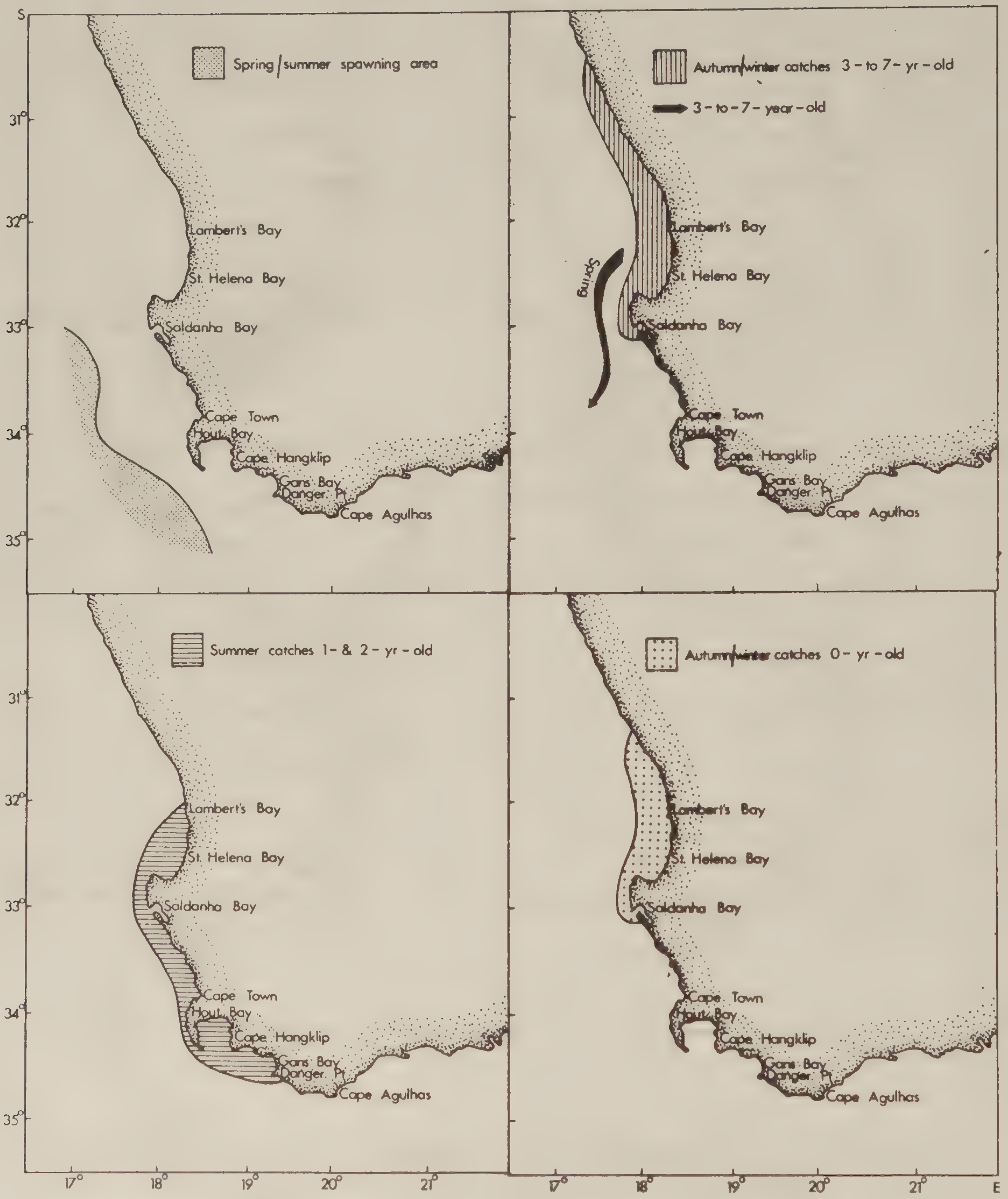
S
31°
32°
33°
34°
35°
Spring/summer spawning area
Autumn/winter catches 3-to 7-yr-old
3-to-7-year-old
Spring
Summer catches 1- & 2-yr-old
Autumn/winter catches 0-yr-old
Lambert's Bay
St. Helena Bay
Saldanha Bay
Cape Town
Hout Bay
Cape Hangklip
Gans Bay
Danger Pt
Cape Agulhas
17°
18°
19°
20°
21°
E

Fig. 4. The main spawning area and catch locations for different age components of the Western Cape *Trachurus trachurus* population (modified from Crawford, 1980a).

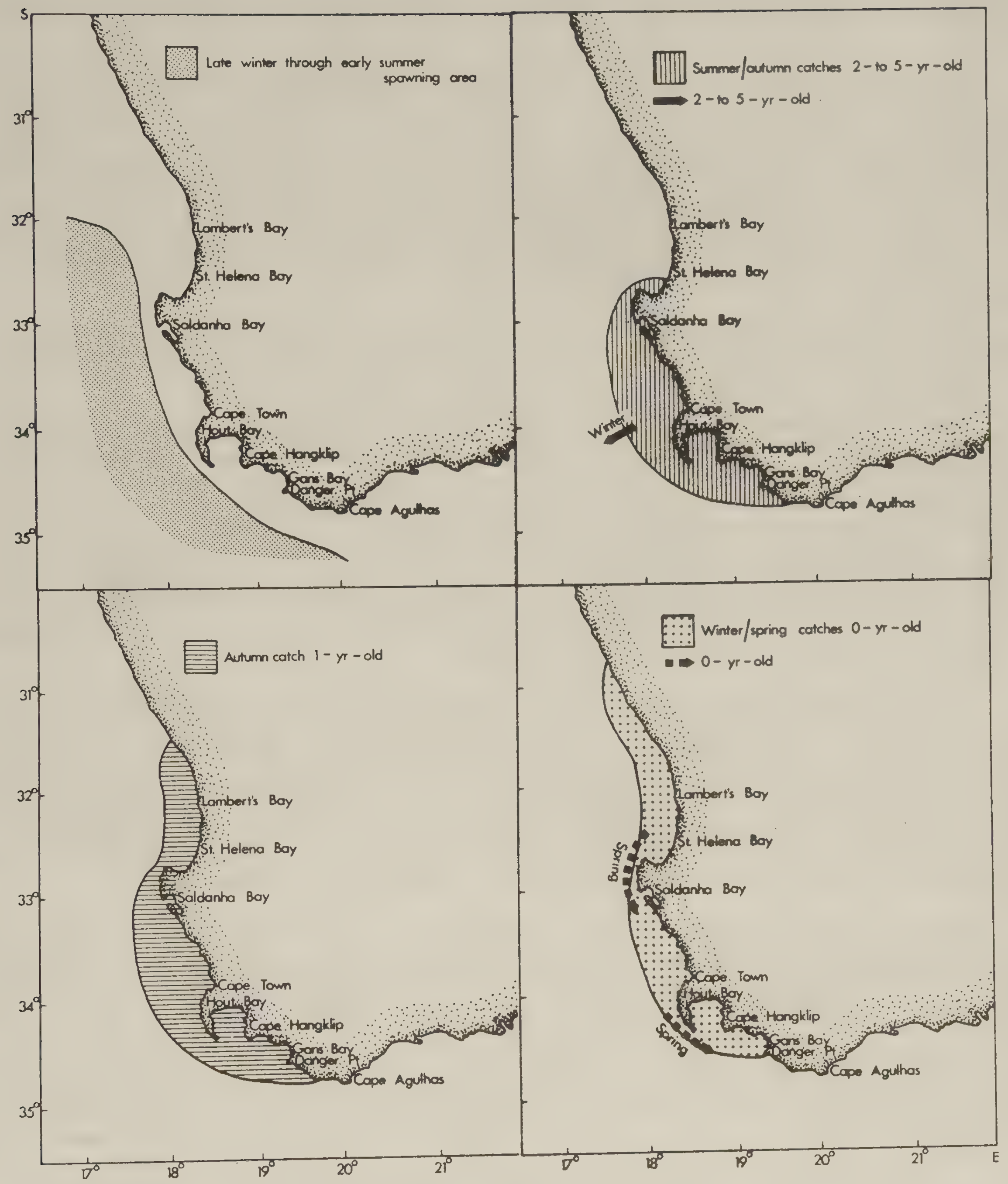
S
Late winter through early summer spawning area
Summer/autumn catches 2 – to 5 – yr – old
2 – to 5 – yr – old
Winter
Autumn catch 1 – yr – old
Winter/spring catches 0 – yr – old
0 – yr – old
Spring
Spring
Lambert's Bay
St. Helena Bay
Saldanha Bay
Cape Town
Hout Bay
Cape Hangklip
Gans Bay
Danger Pt
Cape Agulhas
31°
32°
33°
34°
35°
17°
18°
19°
20°
21°
E

Fig. 5. The main spawning area and catch locations for different age components of the Western Cape *Etrumeus teres* population (modified from Crawford, 1980a).

Shelton and Hutchings (1982) have demonstrated the importance of the Good Hope Jet (Bang and Andrews, 1974) in the northward transportation of anchovy eggs and larvae. Ichthyoplankton spawned east of Cape Point may drift towards the jet in surface currents set in motion by the prevailing southeasterly winds of spring and summer (Duncan and Nell, 1969).

Recruitment of nought-year-olds of anchovies, pilchards, horsemackerel and roundherring takes place along the west coast from mid-autumn onwards. At this age they frequently occur together in mixed shoals and initially are most abundant to the north of St. Helena Bay. In winter, maximum standing stocks of plankton occur in the north of Cape Columbine (de Decker, 1973; Crawford et al., 1980; Shannon and Anderson, 1982). At the onset of spring there is a definite tendency for the young fish to move south into newly initiated regions of upwelling, and maturing anchovies and pilchards continue to the spawning grounds east of Cape Point. At the close of the spawning season they frequently migrate eastwards well past Cape Agulhas.

Five- and six-age group pilchard, adult horsemackerel and adult roundherring have been most available to the purseseine fleets from late summer through winter, moving offshore in other seasons to spawn.

Chubmackerel spawn off Cape Columbine (Fig. 6) in winter and early spring (Baird, 1975; 1977) when onshore currents, set in motion by northwesterly winds, bring relatively warm (14-15°C) water nearer to the coast (Shannon, 1976). Nought-year-olds are fully recruited at the beginning of each year, and occur inshore along the west coast in much the same region as adult roundherring with which they may form mixed shoals (Geldenhuys, 1978). They then assume a progressively more offshore existence, the adults generally only being encountered by purseseiners on their inshore spawning migration off Cape Columbine (Baird, 1978a). By this stage myctophids dominate their diet (Baird, 1978b) and it is noteworthy that Cape Columbine is also the region where most purseseine catches of *Lampanyctodes* are recorded (Crawford, 1980b).

Off South West Africa anchovies spawn inshore between the Cunene River and Mercury Island from late spring to early autumn (King, 1977b; le Clus and Kruger, 1982; le Clus and Melo, 1982). Serial spawning is likely and large adults are more fecund than smaller individuals (le Clus, 1979a). Eggs are carried north by the prevailing currents and most larvae occur in the warmer water north of Walvis Bay (O'Toole, 1977; Badenhorst and Boyd, 1980). Large shoals of juvenile anchovies recruit to the fishery in the vicinity of Walvis Bay, usually from May, whereas adults are caught inshore north of Cape Cross from autumn to early winter (le Clus and Melo, 1982; Thomas et al., 1982).

There are two main centres for the spawning of pilchard eggs: the Walvis Bay vicinity where production takes place from mid-spring to early summer, in seasurface temperatures ranging from 12.0°C to 16.5°C, and between latitudes 19°S and 21°S where eggs are spawned offshore in midsummer and early autumn in water temperatures of 16.5°C to 22.8°C (Stander, 1963; Matthews, 1964; King, 1977; le Clus and Thomas, 1982). Average oocyte mass of spring and early summer spawners is significantly greater than that of pilchards producing eggs in late summer and autumn, perhaps as an adaptation to the lower temperatures encountered (le Clus, 1979b). Dispersal of ichthyoplankton is in a northern direction (O'Toole, 1977) towards a nursery ground for juvenile pilchards near the border of Angola and Namibia/S.W.Africa(Schülein, 1973; Cram, 1977). Nought-year-olds recruit to the fishery from May between Palgrave Point and Walvis Bay, whereas older age groups are caught from autumn (le Clus and Thomas, 1982). The largest size-classes were traditionally caught in the Walvis Bay vicinity (Schülein, 1971; Cram, 1977).

Larvae of *Sufflogobius* were the most important element in ichthyoplankton sampled off South West Africa during the summers of 1972 to 1974 (O'Toole, 1978b). Spawning occurred over a wide area in inshore waters between July and February but was most intensive south of Walvis Bay from spring to early summer (O'Toole, 1978b). Acoustic records indicated that the species was most abundant between Cape Cross and Lüderitz (Cruickshank et al., 1980).

Predators of schooling pelagic fishes include Cape fur seals *Arctocephalus pusillus* (Rand, 1959a), three species of guano producing seabirds, namely Cape gannets *Sula capensis*, jackass penguins *Spheniscus demersus* and Cape cormorants *Phalacrocorax capensis*

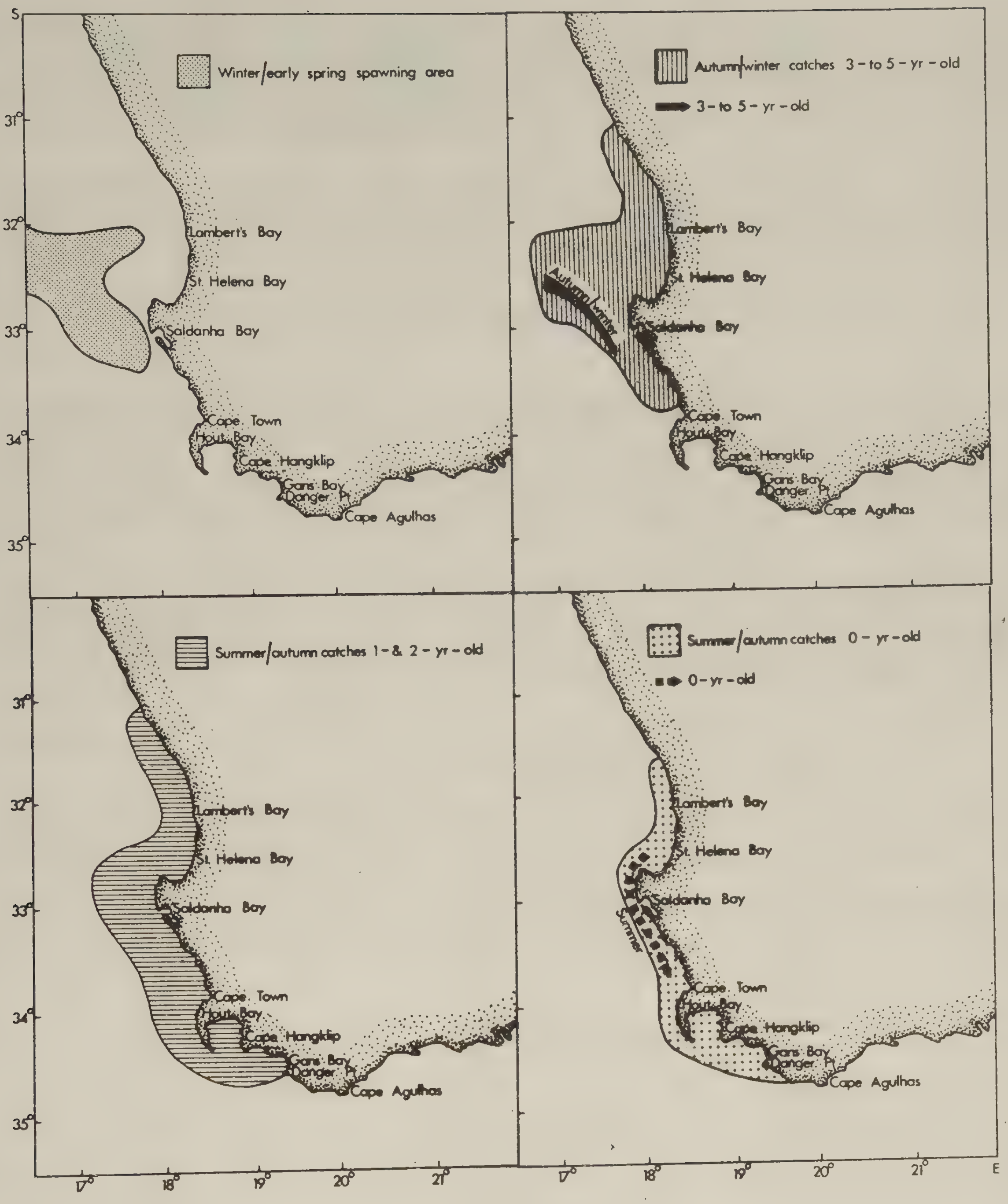
S
Winter/early spring spawning area
Autumn/winter catches 3 - to 5 - yr - old
3 - to 5 - yr - old
Autumn/winter
Summer/autumn catches 1 - & 2 - yr - old
Summer/autumn catches 0 - yr - old
0 - yr - old
Summer
Lambert's Bay
St. Helena Bay
Saldanha Bay
Cape Town
Hout Bay
Cape Hangklip
Gans Bay
Danger Pt
Cape Agulhas
31°
32°
33°
34°
35°
17°
18°
19°
20°
21°
E

Fig. 6. The main spawning area and catch locations for different age components of the Western Cape *Scomber japonicus* population (modified from Crawford, 1980a).

(Davies, 1955; 1956; Rand, 1959b; 1960a; 1960b; Matthews, 1961; Batchelor, 1982; Crawford and Shelton, 1982), various tuna *Thunnus* species (de Jager et al., 1963; Nepgen, 1970), chubmackerel (Baird, 1978b), yellowtail *Seriola lalandi* (Crawford, 1980a) and snoek *Thyrsites atun* (Nepgen, 1979a). Snoek is a migratory fish species being caught off South West Africa from November to January, along the Cape west coast from April to July, and east of Cape Point from June to October (de Jager, 1955; Nepgen, 1979b).

The spawning season for hakes off the Western Cape is late winter to spring (Botha, 1971), whereas newly hatched larvae occur off South West Africa from September to April, particularly in the vicinity of Walvis Bay (O'Toole, 1978a).

## TRENDS IN THE COMMERCIAL FISHERIES

The Western Cape purseseine fishery commenced in 1943, but no accurate records of performance are available prior to 1950. Initially the fishery was largely preoccupied with exploitation of pilchards and horsemackerel (du Plessis 1959), and these two stocks continued to dominate landings until well into the 1960's (Table 1). Annual catches of pilchards in excess of 400,000 tons were recorded in the early 1960's, as a result of exceptionally powerful year-classes formed during the late 1950's (Newman and Crawford 1980). Subsequently recruitment returned to more normal levels, it was not possible to maintain the high yields, and managers of processing plants sought alternative resources to bolster diminishing returns. A small-meshed (13mm) net was introduced in 1964 and exploratory fishing for anchovies was initiated. Since 1966, anchovies have consistently been the major contributor to pelagic catches off the Western Cape, although substantial landings of chubmackerel were also recorded in the mid-1960's.

TABLE 5: Catch, effort and catch per unit effort for South Africa's Western Cape purseseine fishery 1960-1981.

| Year | Combined species catch ('000 t) | Effort (std. boat days) | Catch per unit effort (t/std. boat days) |
|---|---|---|---|
| 1960 | 412,0 | 3,498 | 117,5 |
| 1961 | 490,9 | 3,717 | 132,5 |
| 1962 | 497,3 | 3,936 | 126,6 |
| 1963 | 427,0 | 4,482 | 95,7 |
| 1964 | 425,6 | 5,466 | 77,9 |
| 1965 | 480,1 | 9,580 | 50,1 |
| 1966 | 357,1 | 8,099 | 44,1 |
| 1967 | 509,3 | 12,059 | 42,2 |
| 1968 | 368,6 | 11,110 | 33,2 |
| 1969 | 352,0 | 10,349 | 34,0 |
| 1970 | 358,9 | 11,052 | 32,5 |
| 1971 | 324,9 | 10,126 | 32,1 |
| 1972 | 433,6 | 13,080 | 33,2 |
| 1973 | 451,4 | 12,249 | 36,9 |
| 1974 | 400,5 | 8,720 | 45,9 |
| 1975 | 407,4 | 10,329 | 39,4 |
| 1976 | 407,5 | 8,587 | 47,4 |
| 1977 | 357,2 | 11,168 | 32,0 |
| 1978 | 380,4 | 13,039 | 29,2 |
| 1979 | 380,9 | 10,983 | 34,7 |
| 1980 | 380,5 | 10,065 | 37,8 |
| 1981 | 379,2 | 10,821 | 35,0 |

The combined catch rose to almost 500,000 tons in the early 1960's, but has more recently been limited by a quota system to about 400,000 tons (Crawford, 1981a). Effort escalated considerably after the decline of the pilchard stock through an expansion in total fleet hold capacity, a move towards larger vessels and the introduction of fishing aids (Newman et al., 1979; Crawford, 1981a).

Exploitation of South West African pelagic stocks began in 1947 (Cram, 1977), and until 1968 catches were almost entirely of pilchards (Table 2). More than 1,3 million tons were caught in 1968 but landings then declined rapidly. The 1980 catch amounted to only 11,000 tons. Small-meshed (13 mm) nets were introduced but only became widely used from 1968-1969 (Cram, 1977; Schulein et al., 1978). Since then landings of anchovies have generally exceeded 100,000 tons, a peak catch of 355,000 tons being recorded in 1978. Catches of other species have been insignificant except for 140,000 tons of horsemackerel landed in 1971.

A combined-species catch of over 1,5 million tons was recorded in 1968. Total fish hold capacity of the fleet increased from c. 3,000 tons during 1957-1960 to over 14,000 tons in 1975 (Newman, 1977). However, effort measured in terms of fuel consumption peaked at around 23 million litres in 1969 before decreasing to less than 7 million litres in 1980 as a result of quota restrictions (F.H. Schulein, Sea Fisheries Research Institute, Cape Town).

Since the turn of the century hakes have formed the basis of a substantial demersal trawl fishery off southern Africa, and account for about 70 per cent of the trawl catch (Botha 1970). Catches of hake by the South African fishery (based mainly at Cape Town and in recent years at Saldanha) reached 1,000 metric tons in 1919, increased steadily to 100,000 tons in 1959 (Chalmers 1976) and attained a record of 153,000 tons in 1979 (Botha 1980). After 1962, the Cape hakes also became a sought-after target of distant-water trawlers from several foreign countries. In 1973, 14 different countries achieved a catch of just over one million tons with more than 300 large vessles, thereby establishing the Cape hake fishery as the largest of its kind in the world (Botha, 1980). The local fishery has traditionally confined its fishing activities mainly to the fishing grounds off the Western Cape and to a lesser extent to those off the southern coast of South Africa. Foreign catches of hake have tended to concentrate in areas further north off the coast of South West Africa. After the introduction of a 200 nautical mile exclusive fisheries zone off the Republic of South Africa on 1 November 1977, the hake fishery off South Africa reverted to an almost exclusively local one, as it was before 1962 (Botha, 1980).

## VARIABILITY IN THE ENVIRONMENT

Hutchings and Nelson (1983) developed a timeseries of upwelling indices for the Western Cape for the spring-summer spawning season of pilchards and anchovies. There was considerable variability between seasons, with no clear trend (Fig. 7). Upwelling was poor during the 1965/1966 and 1968/1969 seasons and good during 1974/1975 and 1975/1976. The indices are based on wind records and commences in 1960. In earlier years seasurface temperature information is available for inshore waters from routine research cruises in the St. Helena Bay region (Buys, 1959). A cool anomaly, probably indicative of powerful upwelling, occurred between 1953 and 1957. Warmer temperatures were experienced during the 1952/1953 and 1957/1958 seasons (Fig. 7).

A cool water anomaly for the Walvis Bay region off South West Africa during the mid-1950's lagged behind that of the St. Helena Bay area by about two years (Fig. 7; Stander, 1963). Boyd (1979) investigated variability of seasurface temperature off South West Africa during the period 1969 to 1978 and found it to be low between 1972 and 1975 and during the 1977/1978 spawning season for anchovies.

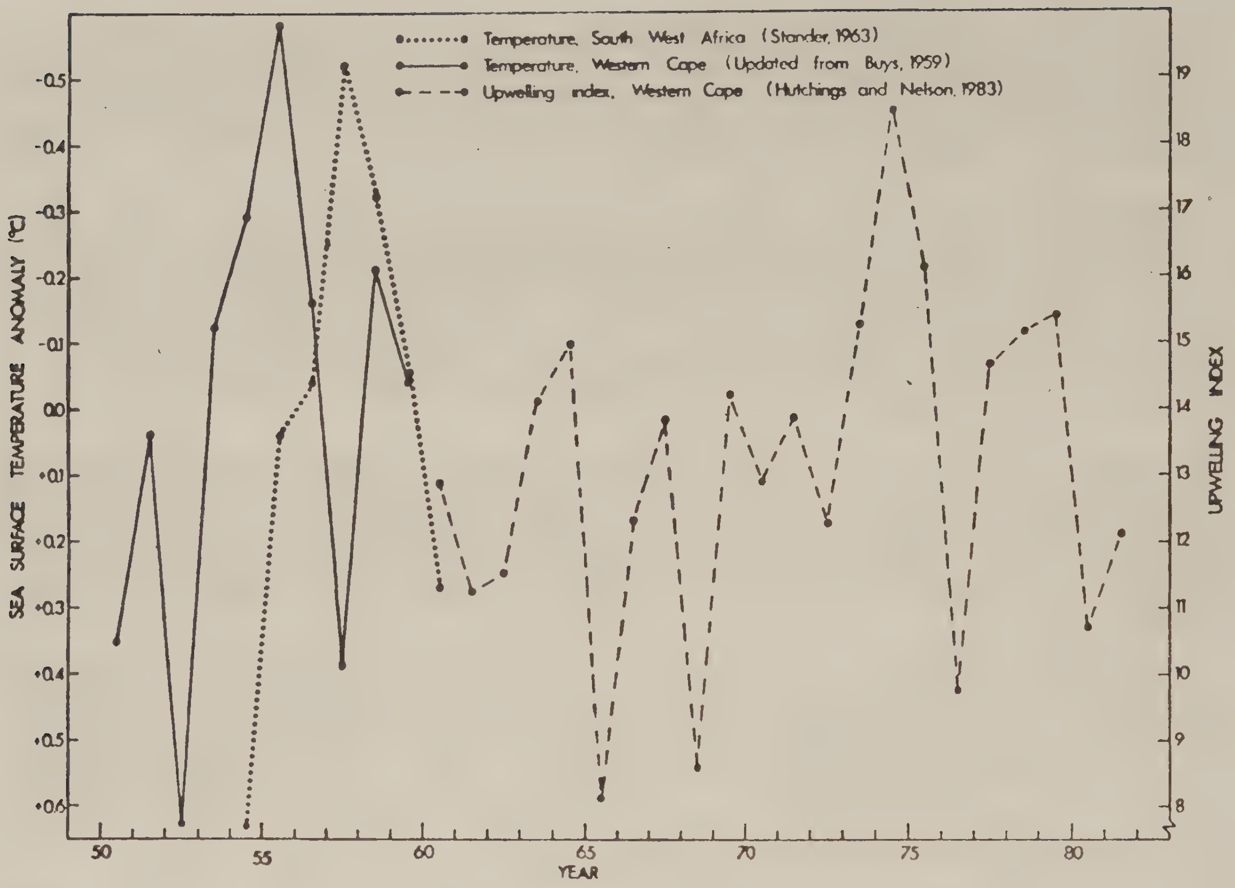

Fig. 7. Seasurface temperature anomalies and upwelling indices for the southern Benguela system, 1950-1982.

## VARIABILITY OF STOCKS DURING THE PERIOD OF EXPLOITATION

### Recruitment

The most extensive timeseries of recruitment (defined in this paper as numbers of nought-year-old fish in the population) available for fisheries of the southeast Atlantic are those derived from Virtual Population Analysis (VPA) (e.g. Centurier-Harris, 1977; Newman and Crawford, 1980; Armstrong *et al.*, 1983; Babayan *et al.*, 1983; le Clus and Melo, 1983; Payne and Leslie, 1983; Thomas, 1983). In all VPA's conducted the natural mortality rate (M) has been assumed constant throughout the period of investigation, and in many instances age compositions of catches in earlier years have been calculated from age at length information pertaining to a subsequent period (Crawford *et al.*, 1978). Additionally the relatively shortlived nature of species exploited by the pelagic fisheries has often meant that cohorts have not contributed in a significant manner to the catches for more than a few years, thereby increasing the likelihood that trends derived from VPA may reflect availability of cohorts to the fishing fleets rather than absolute variations in year-class strength. The purseseine fisheries of the Southern Benguela system catch a mixture of species with preferential fishing for certain species (Crawford 1981a; 1981b) so that VPA indices may also be influenced by availability of other species. For these reasons VPA estimates of recruitment have been compared wherever possible with independent indices to test their validity. On account of assumptions that have to be made regarding terminal mortalities, VPA estimates for the most recent years cannot be considered reliable.

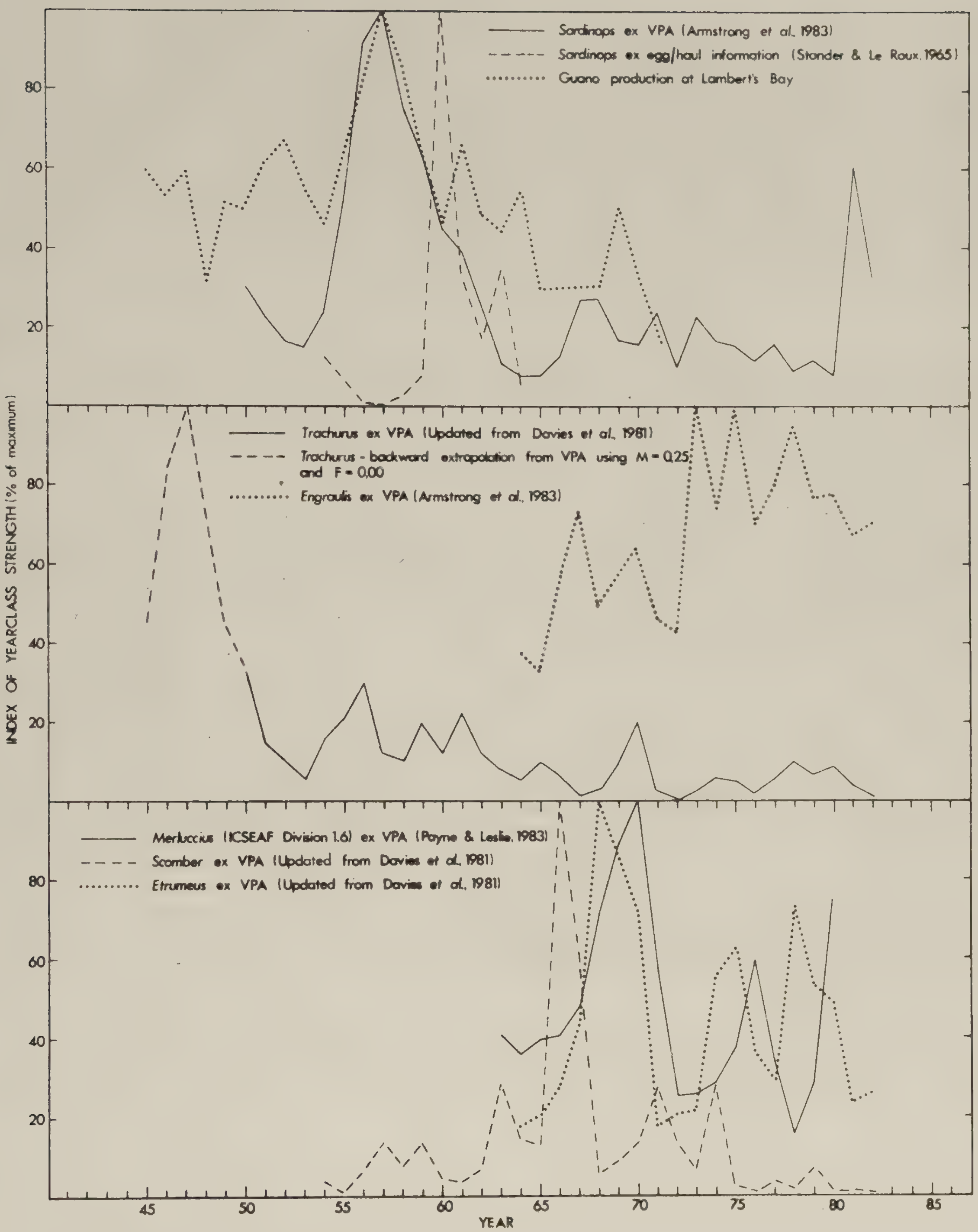

Fig. 8. Indices of recruitment for neritic stocks off the Republic of South Africa's Western Cape, 1945-1982.

### Western Cape *Sardinops* population:

VPA indices suggest that exceptionally good recruitment of pilchards occurred in the mid-1950's, especially 1956 and 1957 (Fig. 8), and as a result spawning biomass peaked during 1960/1961 (Newman and Crawford, 1980; Armstrong et al., 1983). Numbers of pilchard eggs recorded per haul of surface plankton nets also peaked markedly in 1960 (Fig. 8; Stander and le Roux, 1968) and if used as measures of spawning biomass (e.g. Smith, 1972) again suggest a major upward perturbation of recruitment in the mid-1950's. Further evidence for this phenomenon is provided by a large increase in the amount of guano harvested at Lambert's Bay from 1956 to 1958 (Fig. 8). Lambert's Bay is located at the northern extremity of the fishing grounds and in the region where the nought-year-old pilchards recruit to the fishery (Crawford and Shelton, 1978; Crawford, 1980a).

VPA indices further suggest a second, but minor, upswing in recruitment after 1965. From 1969 through 1980 cohort strength of pilchards fluctuated around a level approximately 15 per cent of the 1957 maximum.

### Western Cape *Engraulis* population:

VPA indices of year-class strength for the Western Cape anchovy population are only available from 1964. Recruitment was low in 1964 and 1965, fluctuated around an intermediate level from 1966 to 1972, reached a peak in 1973 and remained high until 1980 (Fig.8). The powerful year-classes from 1973 onwards resulted in a 1979 stock size that was double that of the mid-1960's (Fig. 9). Independent indices of anchovy recruitment are not available, but off the Western Cape handline catches of an important predator, *Thyrsites*, closely followed VPA estimates of total anchovy biomass from 1969 to 1978 ($r = 0{,}708$; $p < 0{,}02$; $n = 10$). This relationship broke down in subsequent years (Fig. 9). The combined annual catch of *Thyrsites* in the Southern Benguela system rose from 8,000 tons in 1973 to 20,000 tons in 1977. It is unlikely to have been greater in previous years, but in 1978 more than 81,000 tons were landed, and this high exploitation possibly influenced stock size. Handline catches of *Thyrsites* off the Western Cape were exceptionally good in 1976 (Fig. 9) and may have resulted from an unusually high availability

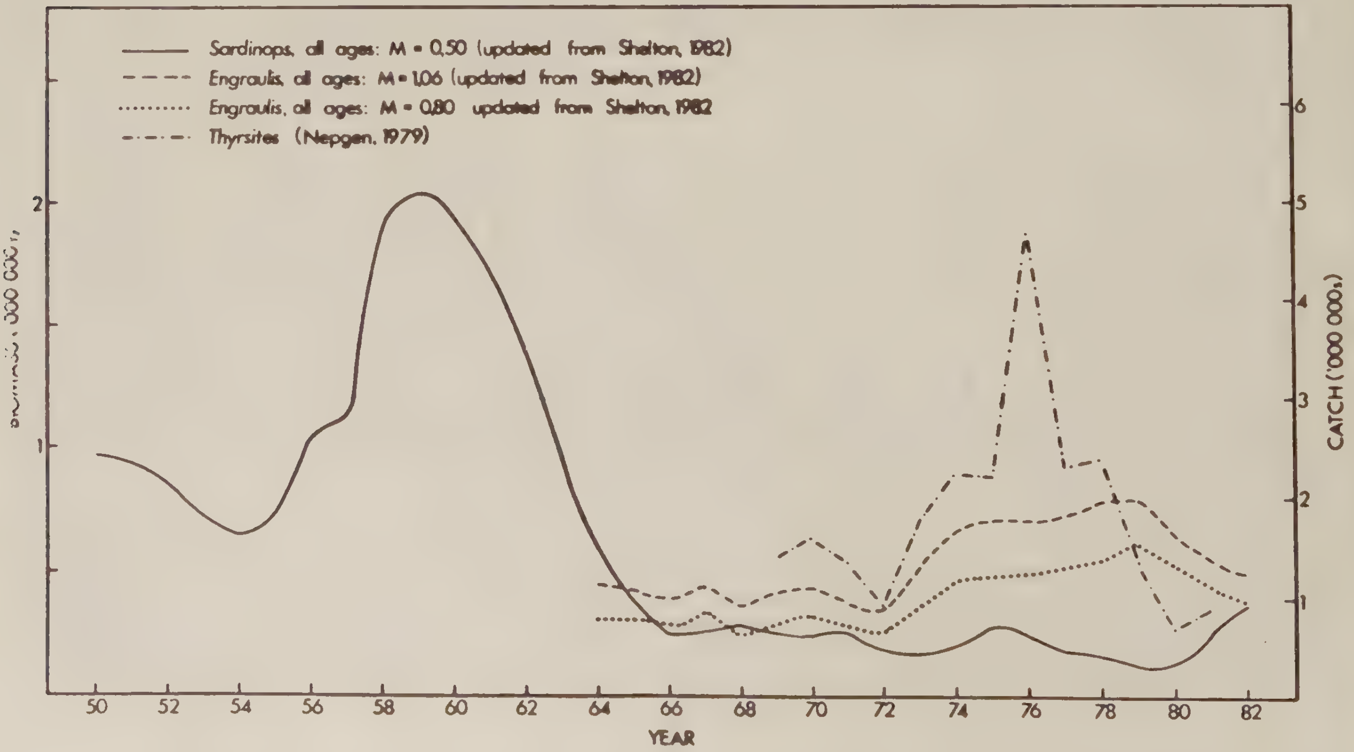

Fig. 9. Trends in biomass of *Sardinops* and of *Engraulis* and in handline catches of *Thyrsites* off the Republic of South Africa's Western Cape, 1950-1982. Natural mortality rates of 0,80 (Newman and Crawford, 1980; Crawford, 1980c) and of 1,06 (MacCall, 1974) have been used for *Engraulis*.

of *Thyrsites* to fishermen in that year. Purseseine catches of pilchards, another major forage (Nepgen, 1979a), were greater in 1976 than in any year since 1965 and 2,5 times the mean for the period 1969-1982 (Table 1). The increased VPA estimates of anchovy recruitment and biomass and the good handline catches of *Thyrsites* in the late 1970's may all have resulted from anchovies being more readily available to both fishermen and predators during this period. However, consistency of the trends makes an absolute increase in the biomass of anchovies after 1972 the more likely explanation. The large increase in recruitment in 1973 and the plentiful cohorts that followed could then be regarded as the most significant events in the dynamics of the anchovy stock since exploitation was initiated.

### Western Cape *Trachurus* population:

Between 1950 and 1958 annual length compositions of purseseine catches of horsemackerel off the Western Cape were characterized by the progression of a distinct mode (Fig. 10). Geldenhuys (1973) identified this as consisting mainly of the 1946, 1947 and 1948 year-classes, so that the high catches of the early 1950's appear to have resulted from powerful recruitment during the late 1940's (Fig. 8). Only 65 per cent of horsemackerel otoliths have discernible age rings (Gendenhuys, 1973) making VPA of doubtful reliability (Newman and Crawford, 1980). VPA applied to the best available age information suggests that recruitment since 1950 has been considerably lower than during the late 1940's. A number of minor peaks, separated by intervals of up to five years, occurred between 1956 and 1970. Since 1970 recruitment has never exceeded 10 per cent of the 1947 maximum (Fig. 8).

### Western Cape *Scomber* population:

VPA suggests that powerful recruitment of chubmackerel occurred during 1966 and 1967 (Fig. 8). The highest chubmackerel catches on record were landed between 1967 and 1969 (Table 1), when much of the harvest was netted close inshore (Crawford,1981d). It is possible that environmental factors may have resulted in increased availability of chubmackerel to the purseseine fleet during this period. However, catches of adult chubmackerel pursed offshore peaked during 1969 and 1970 at about 60,000 tons before declining to negligible quantities by 1975 (Baird, 1978a). The development of the 1966 and 1967 cohorts can be traced on distributional charts of catches and their length compositions, and from the charts it is evident that the 1966 and 1967 year-classes provided the bulk of the offshore catches of adults until 1971 (Crawford, 1981d). With their passing from the fishery the chubmackerel catch declined.

Minor increases in year-class strength of chubmackerel have been estimated by VPA for the late 1950's, 1963, 1971 and 1974, but even the best of these was less than 30 per cent of the 1966 peak (Fig. 8). Since 1974 recruitment has been consistently poor.

### Western Cape *Etrumeus* population:

As with the anchovy population, VPA indices of roundherring recruitment are only available from 1964, when commercial fishing with the smallmeshed net was first permitted. Round herrings have relatively large scales, which they shed readily when disturbed. This frequently leads to clogged meshes and a net that is both difficult to purse and that will later require considerable time and effort to clean. Fishermen, therefore, generally avoid roundherrings when they can be recognized and when other fish are plentiful (Crawford, 1981b), complicating interpretation of VPA. Recruitment appears to have been at its highest from 1968 to 1970 with peaks also during 1974/75 and 1976/77. Catch per unit effort indices for the mixed-species purseseine fishery of the Western Cape were low from 1968 to 1972 (Table 5, Crawford 1981a), that is after the decline of the pilchard stock but before the increase of the anchovy population. A scarcity of fish during this period may have resulted in a higher proportion of effort being directed towards shoals of roundherrings. However, the 1969 and 1970 year-classes persisted into the catches of 1972 and 1973 respectively (Geldenhuys, 1978).

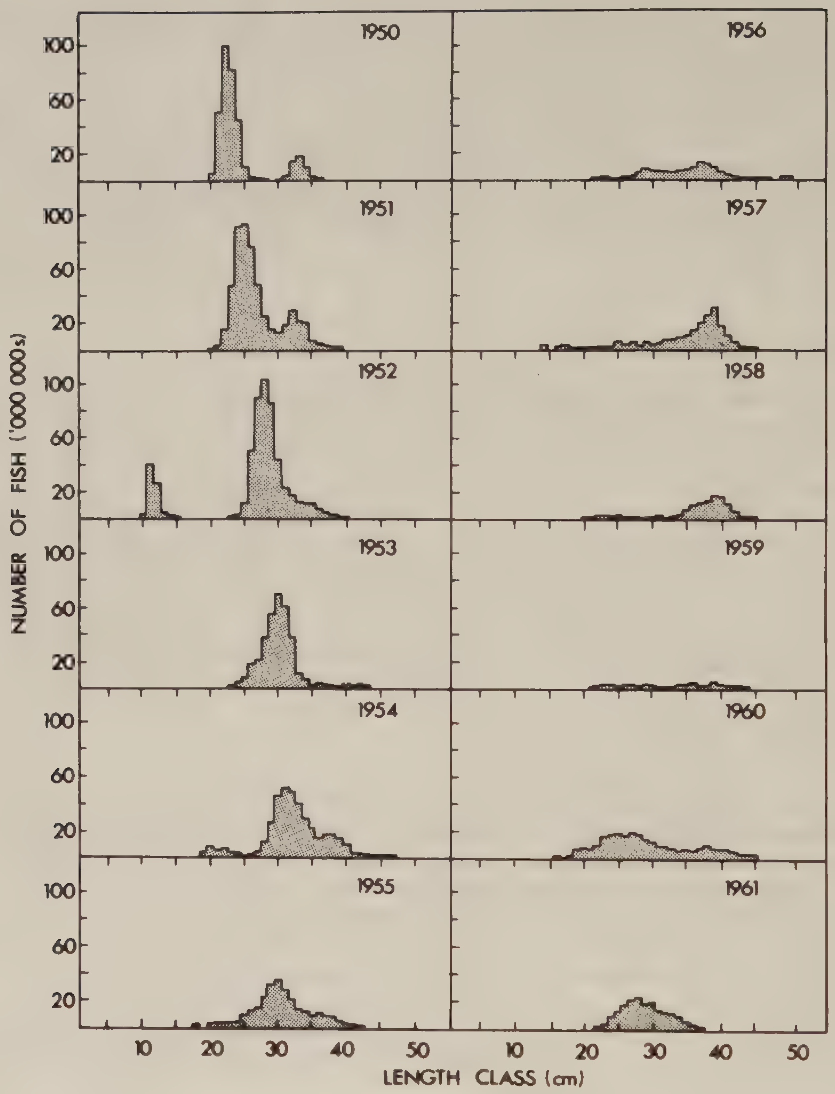

Fig. 10. Caudal length distribution of purseseine catches of *Trachurus* off the Republic of South Africa's Western Cape, 1950-1961.

## *Merluccius* spp. in ICSEAF Division 1.6:

VPA estimates for *Merluccius* spp. in ICSEAF Division 1.6 (Payne and Leslie, 1983) indicate a large increase in year-class strength between 1968 and 1971 and a smaller peak in 1976. The cohorts of other years were moderate. (The 1980 increase cannot be considered reliable at this stage.) Selection factors for hake are 10, 80 and 100 per cent for fish aged one, two and three or older respectively (Payne and Leslie, 1983). The good year-class of 1976 appears to have improved catch rates in the late 1970's (Table 3). However, although the apparently powerful cohorts of the late 1960's and early 1970's were detected by VPA's at an early stage (Newman et al., 1976), they had no noticeable impact on indices of catch per unit effort in the early 1970's. From 1971 to 1973 there were large increases in both catch and effort (Table 3) as foreign participation in the fishery peaked.

## South West African *Sardinops* population:

Age information for catches of pilchards off South West Africa are only reliable from 1967 (Thomas, 1979; 1983). Earlier Nawratil (1960) had used scales to estimate age composition of the catches, but Newman (1970a) discussing the results of a tagging experiment concluded that Nawratil's (1960) age compositions were invalid. Off South West Africa and Angola catches at the northern extremity of the pilchard fishing grounds are often of the smaller size-classes (Monteiro, 1962; Schulein, 1971). Angolan catches (from Schulein 1971) were exceptionally high during 1956 and 1957 (Fig. 11), suggesting powerful recruitment in these years. Numbers of pilchard eggs recorded per haul of surface plankton nets in the vicinity of Walvis Bay peaked markedly three years later. The steep decline in this parameter after 1960 has been attributed to an oceanographic anomaly resulting in conditions unsuitable for sexual development of pilchards (Stander and de Decker, 1969), but decreasing biomass of spawners following a return to more normal levels of recruitment may equally well have been the cause.

VPA (Thomas, 1983) indicates that recruitment increased from 1969 to a maximum in 1972 and then declined sharply (Fig. 11). The year-classes of the early 1970's gave rise to improvements in overall stock size and biomass of spawners, trends that are borne out by catch rates, aerial estimates of stock size and egg surveys (Fig. 12) as discussed fully by Butterworth (1980).

## South West African *Engraulis* population:

VPA estimates of recruitment of anchovies off South West Africa (le Clus and Melo, 1983) fluctuated around a relatively stable level from 1972 to 1981 (Fig. 11). Ageing in earlier years is considered unreliable. The 1982 value is low but only preliminary. The strongest year-class occurred in 1978 and there were also peaks in 1973, 1975 and 1980. Apparently no increase in recruitment has been maintained over two successive years. Independent estimates of anchovy egg production from the 1978/79 to 1980/81 spawning seasons (le Clus and Melo, 1982) match trends in recruitment of one year earlier (Fig. 11). Anchovies mature from one year of age (Crawford, 1981e; Armstrong et al., 1983).

## South West African *Trachurus* population:

Off South West Africa VPA indices of recruitment of horsemackerel (Babayan et al., 1983) increased markedly from 1967 through 1978, with minor fluctuations (Fig. 11). A large catch of juvenile fish was recorded by the South West African purseseine fleet in 1971 (Table 2; Newman and Centurier-Harris, 1977) but foreign trawlers using midwater nets have been responsible for the bulk of the catches in other years.

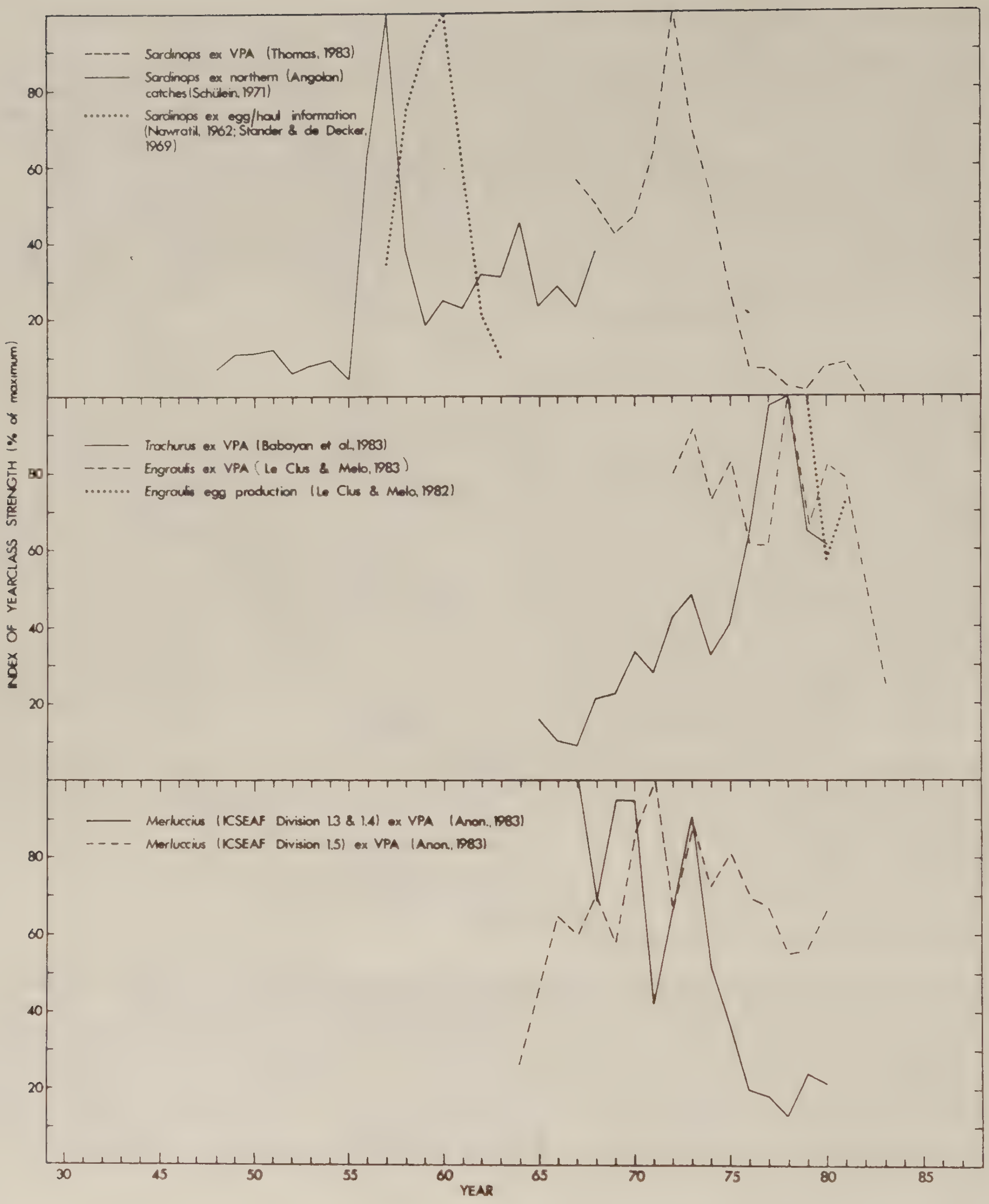

Fig. 11. Indices of recruitment for neritic stocks off South West Africa 1948-1982.

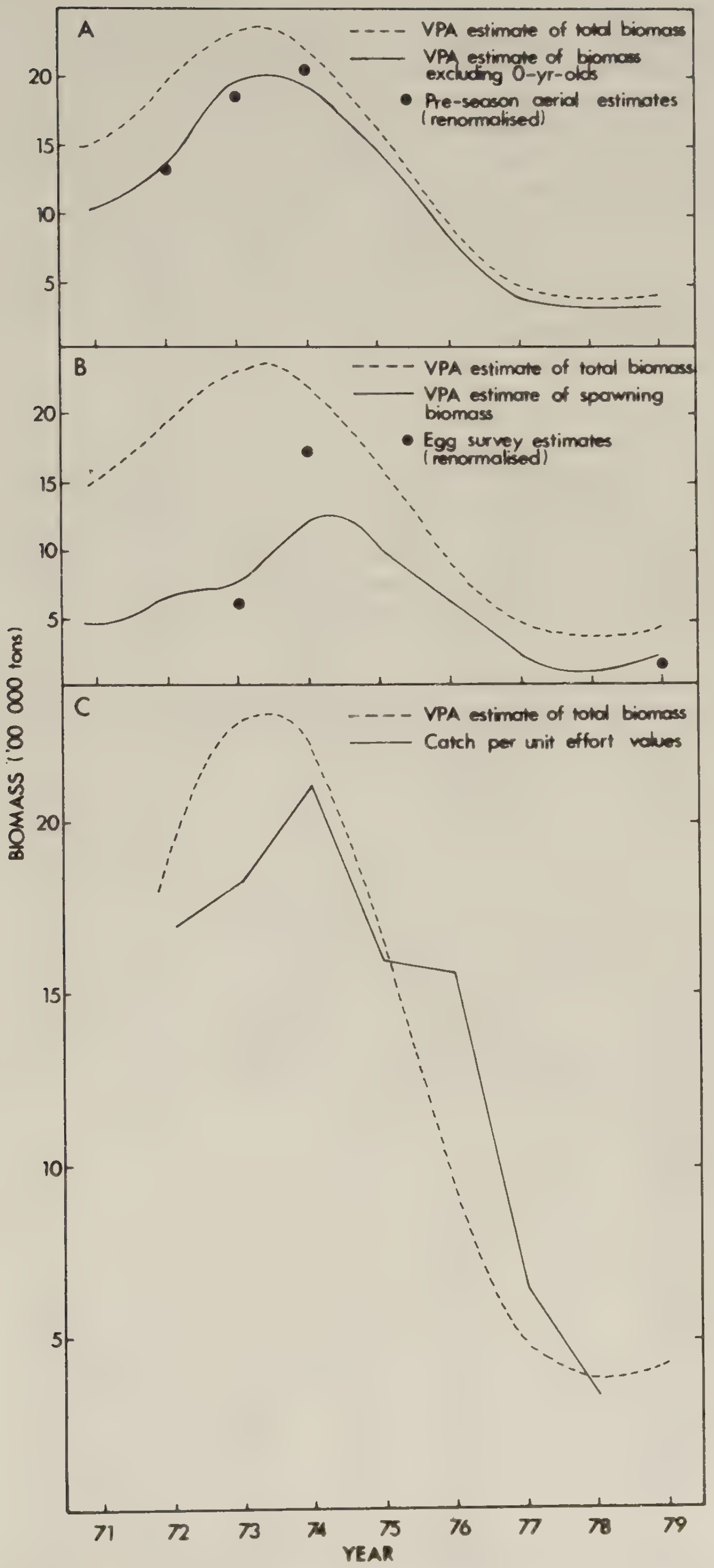

Fig. 12. Trends in Virtual Population estimates of biomass of *Sardinops* compared with (A) aerial estimates of stock abundance, (B) estimates of abundance from egg surveys and (C) catch rates, 1971-1979 (modified from Butterworth, 1980).

*Merluccius* spp. in ICSEAF Divisions 1.3, 1.4 and 1.5:

The fisheries for hake in ICSEAF Divisions 1.3, 1.4 and 1.5 are multinational. Assessments have previously been based on the assumption that one population was responsible for catches from Divisions 1.3 and 1.4 and a second for those from Division 1.5 (e.g. Newman et al., 1976a; 1976b). Preliminary results from a recent study of stock identity based on meristic characters confirm the existence of two populations within these Divisions, but indicate that the boundary between the two occurs at about latitude 23°S near the middle of Division of 1.4 (Lleonart et al., 1983). Therefore not too much significance can be attached to VPA indices of recruitment for the two formerly recognized populations (Fig. 11). Year-class strength for hakes in Divisions 1.3 and 1.4 apparently declined, with fluctuations, by approximately 80 per cent since 1967, whereas the general recruitment trend for hakes in Division 1.5 was an increase from 1964 through 1971 and subsequently a moderate decline.

## Biomass

VPA estimates of biomass for some of the more important fish stocks in the south-eastern Atlantic are presented in Tables 6 and 7. During the 1950's and early 1960's *Sardinops* was the major resource off the Western Cape and South West Africa, but in both regions biomasses subsequently declined to less than 10 per cent of the maximum levels. After fluctuating between 600,000 and one million tonnes from 1950 to 1955, the Western Cape population reached a size of about two million in 1959, but fell to below 200,000 tonnes in the early 1970's (Newman and Crawford, 1980; Davies et al., 1981; Shelton, 1982).

TABLE 6: Biomass estimates ('000 t) for some neritic fish populations off South West Africa, 1957-1982 (from VPA unless otherwise indicated)

| Year | *Sardinops* | *Trachurus* | *Engraulis* | *Merluccius* ICSEAF Divisions 1.3 & 1.4 | *Merluccius* ICSEAF Division 1.5 |
|---|---|---|---|---|---|
| Ages | All | 1 + older | All | 2 - 7 | 2 - 9 |
| Source | Thomas (1983) | Modified from Babayan et al., (1983) | Le Clus & Melo (1983) | Anon (1983) | Anon (1983) |
| 1957-1960 | 5,670× | | | | |
| 1963 | 6,804× | | | | |
| 1964 | 6,804× | | | | |
| 1965 | 6,804× | | | | 729 |
| 1966 | 6,804× | 1,092 | | | 706 |
| 1967 | 5,955 | 982 | | | 726 |
| 1968 | 4,161 | 947 | | 1,063 | 735 |
| 1969 | 2,402 | 1,047 | | 1,130 | 643 |
| 1970 | 1,449 | 1,177 | | 1,230 | 606 |
| 1971 | 1,376 | 1,439 | | 1,281 | 626 |
| 1972 | 1,733 | 1,477 | 646 | 1,451 | 689 |
| 1973 | 2,114 | 1,832 | 748 | 1,033 | 730 |
| 1974 | 2,125 | 2,056 | 572 | 878 | 624 |
| 1975 | 1,582 | 2,203 | 551 | 1,025 | 625 |
| 1976 | 836 | 2,461 | 504 | 1,061 | 824 |
| 1977 | 315 | 2,583 | 554 | 775 | 841 |
| 1978 | 100 | 3,085 | 739 | 557 | 481 |
| 1979 | 48 | 3,551 | 481 | 392 | 462 |
| 1980 | 51 | 3,799 | 463 | 294 | 460 |
| 1981 | 125 | 3,821 | 519 | 333 | 432 |
| 1982 | 91 | | 289 | | |

× From tagging (Newman, 1970a)

TABLE 7: VPA estimates of biomass ('000 t) for some neritic fish populations off South Africa's Western Cape, 1950-1982 (*Merluccius* from Payne or Leslie, 1983; others modified from Davies *et al*., 1981).

| Year | *Sardinops* | *Trachurus* | *Engraulis* | *Scomber* | *Etrumeus* | *Merluccius* |
|---|---|---|---|---|---|---|
| 1950 | 960 | 620 | | | | |
| 1951 | 950 | 690 | | | | |
| 1952 | 861 | 670 | | | | |
| 1953 | 713 | 610 | | | | |
| 1954 | 641 | 552 | | 38 | | |
| 1955 | 740 | 440 | | 51 | | |
| 1956 | 1 040 | 362 | | 48 | | |
| 1957 | 1 130 | 330 | | 37 | | |
| 1958 | 1 900 | 252 | | 56 | | |
| 1959 | 2 040 | 220 | | 67 | | |
| 1960 | 1 940 | 230 | | 69 | | |
| 1961 | 1 700 | 171 | | 70 | | |
| 1962 | 1 400 | 151 | | 42 | | |
| 1963 | 980 | 92 | | 45 | | |
| 1964 | 592 | 94 | 310 | 80 | 22 | 565 |
| 1965 | 382 | 86 | 310 | 69 | 34 | 618 |
| 1966 | 243 | 59 | 290 | 144 | 48 | 639 |
| 1967 | 260 | 48 | 343 | 250 | 58 | 577 |
| 1968 | 290 | 45 | 250 | 201 | 52 | 548 |
| 1969 | 241 | 46 | 290 | 160 | 47 | 563 |
| 1970 | 233 | 5 | 323 | 110 | 62 | 563 |
| 1971 | 252 | 3 | 283 | 90 | 57 | 632 |
| 1972 | 182 | 4 | 260 | 102 | 50 | 616 |
| 1973 | 180 | 3 | 370 | 96 | 46 | 468 |
| 1974 | 202 | 1 | 460 | 80 | 40 | 324 |
| 1975 | 280 | 1 | 483 | 102 | 80 | 231 |
| 1976 | 250 | 2 | 500 | 87 | 100 | 218 |
| 1977 | 184 | 4 | 520 | 111 | 120 | 160 |
| 1978 | 171 | 3 | 544 | 6 | 97 | 199 |
| 1979 | 130 | 5 | 610 | 10 | 48 | 180 |
| 1980 | 130 | 11 | 520 | 14 | 63 | 158 |
| 1981 | 270 | 21 | 440 | 25 | 80 | 131 |
| 1982 | 370 | 3 | 380 | 33 | 82 | |

The South West African population was estimated from tagging at 5,67 million tonnes for the period 1957-1960 and 6,80 million tonnes between 1963 and 1966 (Newman, 1970a). The VPA estimate for 1967 was 6 million tonnes but this had decreased to 1,4 million tonnes by 1976 (Thomas, 1983). The decline was then arrested by favourable recruitment, leading Cram (1977) to speculate that stock had recovered. In retrospect it is evident that the "recovery" was shortlived, the biomass climbing to slightly over 2 million tonnes in 1973 and 1974 but then plummeting to less than 50,000 tonnes by 1979 (Thomas, 1983).

Biomass indices for the horsemackerel population of the Western Cape decreased markedly after the early 1950's (Table 7). The indices are based on purseseine catches only, although the species is also caught demersally (de Villiers, 1977). The population appears to have the centre of its distribution offshore (Fig. 4; Crawford, 1980c) and catchability to purseseiners increases with increasing population size (in prep.), suggesting that a large stock expands its geographic distribution and in so doing becomes more readily available to the purseseine fleet.

Biomass of the chubmackerel population of the Western Cape increased from a level of about 50,000 tonnes during the 1950's to 250,000 tonnes in 1967, largely as a result of powerful 1966 and 1967 year-classes (Newman and Crawford, 1980). The stock then decreased with depressed biomasses being calculated for the late 1970's (Table 7). Biomass levels of hakes in each of the ICSEAF Divisions considered have also deteriorated in recent years (Tables 6 and 7), whereas that of the anchovy population off South West Africa remained fairly stable during the 1970's fluctuating between 450,000 and 750,000 tonnes (Table 6).

Increased population sizes have recently been observed for three stocks in the south-east Atlantic, those of anchovy and roundherring off the Western Cape and horsemackerel off South West Africa (Tables 6 and 7). In their respective regions the anchovy and horse-mackerel stocks are currently the most important of those for which biomass estimates are available. Interestingly both increased in a sigmoid fashion, following large decreases in the local pilchard populations, and they attained their maxima 10 to 13 years after the collapses of the pilchard stocks were complete (Fig. 9 and 13).

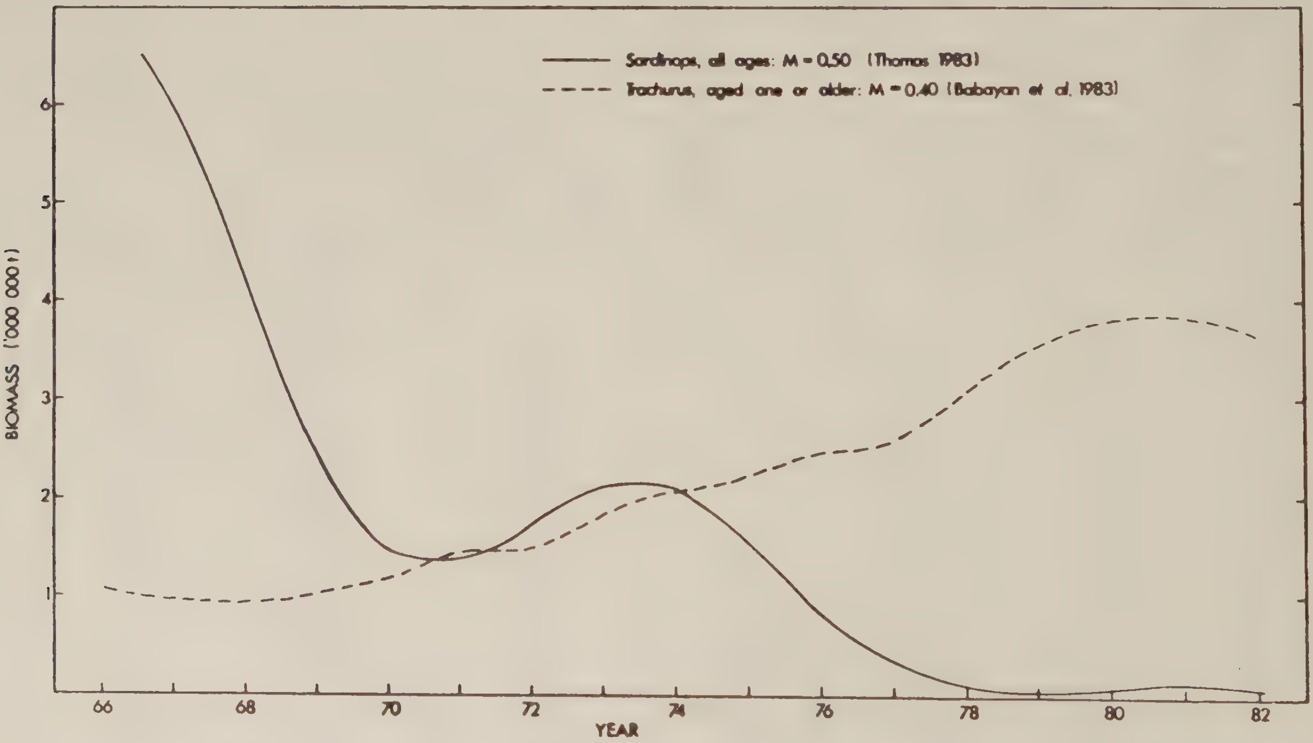

Fig. 13. Trends in biomass of *Sardinops* and *Trachurus* off South West Africa, 1966-1982.

The Verhulst-Pearl logistic growth curve was applied to both the Western Cape *Engraulis* and South West African *Trachurus* populations in a manner similar to the catch-corrected model described by MacCall (1980). Constants for the instantaneous natural rate of decrease in biomass (M-G) were derived using mass at age information and instantaneous natural mortality rates of 0,8 and 0,4 for anchovies and horsemackerel respectively (Crawford, 1980c; Babayan *et al.*, 1983). For anchovies M-G was calculated for ages one to three, as contrasted *with ages* two to three compared by MacCall (1980), on account of the large proportion of young anchovies in commercial catches off the Western Cape (Crawford *et al.*, 1978). Ages two to ten were considered for horsemackerel since all contribute *to the* midwater trawl catch (Babayan *et al.*, 1983). Each year's VPA estimate of biomass (Bt) was reduced by the natural rate *of decrease* and incremented by the next year's recruitment (Rt + 1) to provide an estimate of the biomass ($\bar{B}t + 1$) that would have occurred at the beginning of the next year under conditions of no fishing. Thus

$$\bar{B}t + 1 = Bt + Rt+1.$$

Assuming a constant $B_{\infty}$, which was estimated at slightly above the maximum biomass observed each pair of Bt and $\bar{B}t+1$ was used to derive the value r in the logistic equation

$$Bt = B_{\infty}(1+e^{\sim}A-rt)$$

A mean r was then calculated and used as an initial estimate in the iterative model described by MacCall (1980) to obtain final estimates of $B_{\infty}$, A and r.

The difference between $\bar{B}t+1$ and Bt+1, that is the difference between the projected biomass under conditions of no fishing and the VPA estimate of biomass based on actual exploitation, was taken to be the "equivalent end-of-year catch" (*cf.* MacCall, 1980). Biomass was then incremented assuming logistic growth and decreased after each year by the equivalent end-of-year catch. Timeseries of biomasses computed in this way are compared with estimates calculated by VPA in Fig. 14. Good agreement suggests that the Verhulst-Pearl logistic equation describes in a reasonable manner growth of the Western Cape anchovy and South West African horsemackerel populations in recent years.

## Range

During the early years of commercial exploitation of pelagic species off the Western Cape substantial quantities of large adult pilchards were regularly caught off St. Helena Bay (du Plessis, 1959). On the basis of length information these fish are believed to have been aged five or older (Crawford *et al.*, 1978). Following the decline of the pilchard stock in the late 1960's and *the introduction* of small-meshed nets in 1964 adult pilchards ceased to occur in significant numbers west of Cape Point. The bulk of the adult population, comprising fish aged two to four, currently inhabits the waters east of Cape Point (Crawford, 1981f). Results of historical egg surveys suggest that when adult pilchards were abundant off St. Helena Bay spawning also occurred east of Cape Point (Crawford, 1981f). The depletion of the pilchard stock was thus characterized by a contraction in the distribution of adults, and the contraction was towards the warmer waters of the region.

A similar phenomenon appears to have taken place off South West Africa. Prior to the collapse of the pilchard fishery shoals of large fish were encountered well to the south of Walvis Bay, and were exploited by boats operating from Lüderitz (Schülein, 1971). After the stock had been substantially depleted boats from Lüderitz were forced to fish north of Walvis Bay, and eventually the processing plant at Lüderitz ceased operations. Over the period 1959 to 1973 the fishing range of boats operating from Walvis Bay was related to stock size, boats travelling further to the north during periods of low abundance (Cram, 1977). Quantities of pilchard eggs spawned off Walvis Bay declined substantially following the resource reduction (Matthews, 1964; King, 1977). Spawning still occurs in warmer water further north (King, 1977; le Clus and Kruger, 1982).

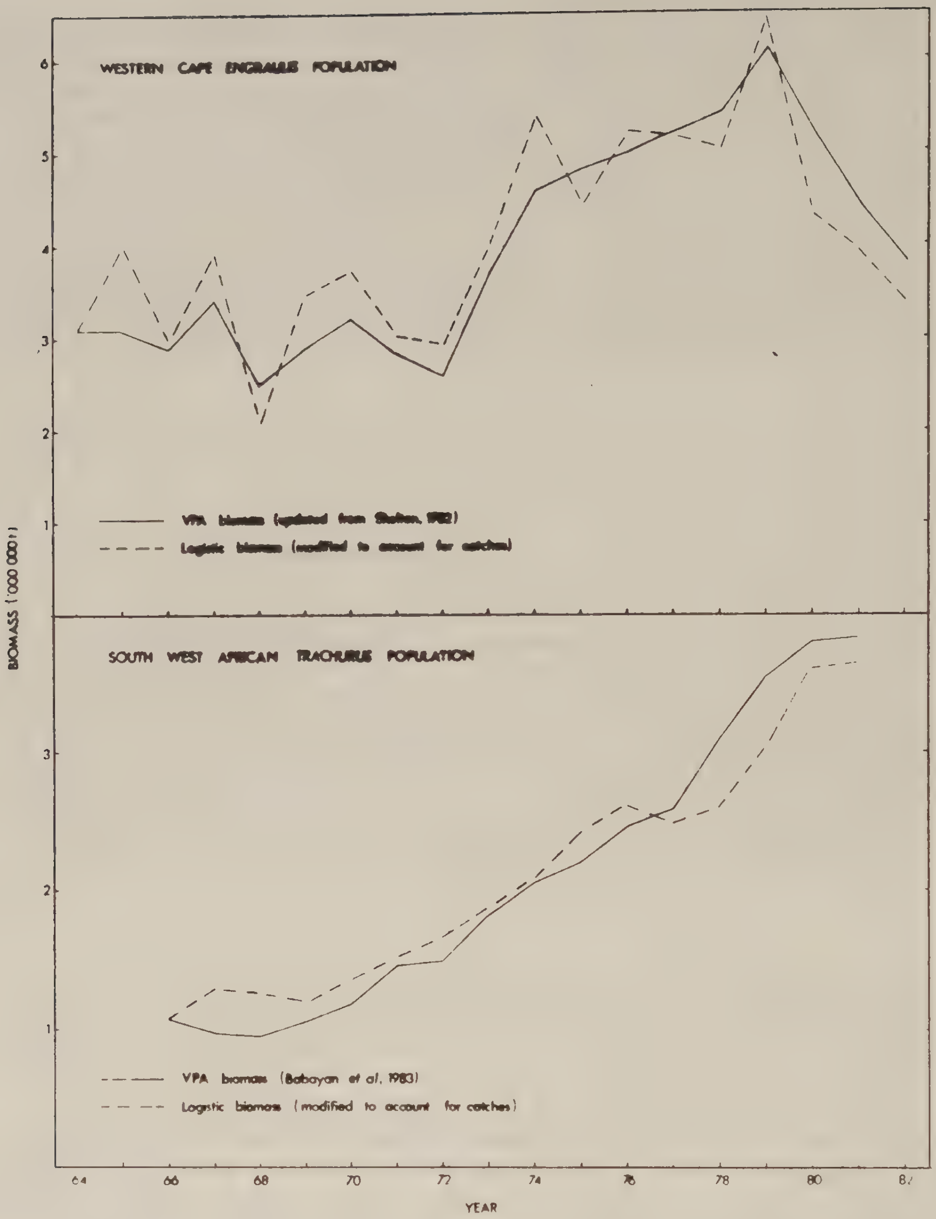

Fig. 14. Population growth of the Western Cape *Engraulis* and South West African *Trachurus* populations as estimated by Virtual Population Analysis and by fitting the logistic growth equation, 1964-1982.

# VARIABILITY OF RESOURCES PRIOR TO THE INITIATION OF COMMERCIAL EXPLOITATION

## Recruitment and biomass

The seabird island at Lambert's Bay is located at the centre of the recruitment grounds for pilchards, anchovies, horsemackerel and roundherring off the Western Cape (Crawford, 1980a). Since the late 1890's there have been three large peaks in the amount of guano collected at this island, separated by intervals of approximately 30 years (Fig. 15). The final peak was significantly correlated ($r = 0.783$; $p < 0.001$; $n = 20$) with the eruption of pilchard recruitment during the late 1950's, leading to speculation that similar powerful cohorts may have been formed during the 1890's and 1920's (Crawford and Shelton, 1978; Newman and Crawford, 1980). The peak of the 1890's was significantly correlated ($r = 0.804$; $p < 0.02$; $n = 7$) with catch rates of snoek, a major predator of pelagic fishes in the southern Benguela system (Crawford and Shelton, 1978), and that of the 1920's with handline catches of snoek off the Western Cape ($r = 0.739$; $p < 0.01$; $n = 18$). At many seabird islands off southern Africa, including Lambert's Bay, the guano harvest is related to numbers of breeding seabirds (Crawford and Shelton, 1978).

Prior to the initiation of commercial exploitation of pelagic fishes off southern Africa, guano harvests at seabird islands were dependent on availability of shoaling pelagic fishes (Hutchinson, 1950). Losses of guano caused by rain was also of importance (Hutchinson, 1950), but global economic factors apparently exerted little influence. In an attempt to nullify effects of rain, guano harvests at islands off the Republic of South Africa and off South West Africa were considered as the moving averages of three years (Fig. 16). Historical accumulations of guano had been cleared by the middle of the nineteenth century (Hutchinson, 1950). Trends for the two regions were similar until the mid-1940's, that is before the commencement of purseseine fishing. There were large increases in production from 1900 through the mid-1920's, followed by decreases in both regions. Yields were again high in the late 1930's and early 1940's. Trends at islands off South West Africa, in more recent years may have been influenced by the construction of guano platforms between Walvis Bay and Cape Cross from 1930 (Fig. 1), although at the same time natural breeding sites in the Walvis Bay vicinity were lost through islands in lagoons becoming joined to the mainland (Rand, 1952; Cooper *et al.*, 1982). Guano harvests at islands off South Africa stabilized at about 2000 t in the 1950's before declining to half this level from the early 1960's. This decline corresponded to the depletion of the Western Cape pilchard stock (Crawford and Shelton, 1978). A decline of similar magnitude at islands off South West Africa during the late 1960's occurred coincidentally with the collapse of the local pilchard stock (Table 7).

## Range

Neither pilchards nor anchovies were recorded as prey items of gannets breeding at Bird Island, near Port Elizabeth, in the 1930's (Rand, 1959b). Sample size is not known, but from 1978 to 1981 ($n = 2031$) these two species contributed 60 per cent of the diet (Batchelor, 1982). Numbers of gannets breeding at Bird Island have increased markedly in recent years, as have population sizes of penguins and Cape cormorants at islands east of Cape Point (Randall and Ross, 1979; Crawford and Shelton, 1982). It appears that abundance of pilchards and anchovies off Port Elizabeth was low at the start of the century, whereas it is now likely to be substantial.

Off South West Africa guano production at each of the major islands was high during the 1920's (Fig. 17). There were subsequent declines at each centre, but those at the two northernmost islands (Mercury and Ichaboe) were considerably less severe than at islands located further south. If the exceptional guano yields of the 1920's resulted from a high biomass of pelagic fishes, it is likely that as abundance of fish declined the stocks contracted to the north.

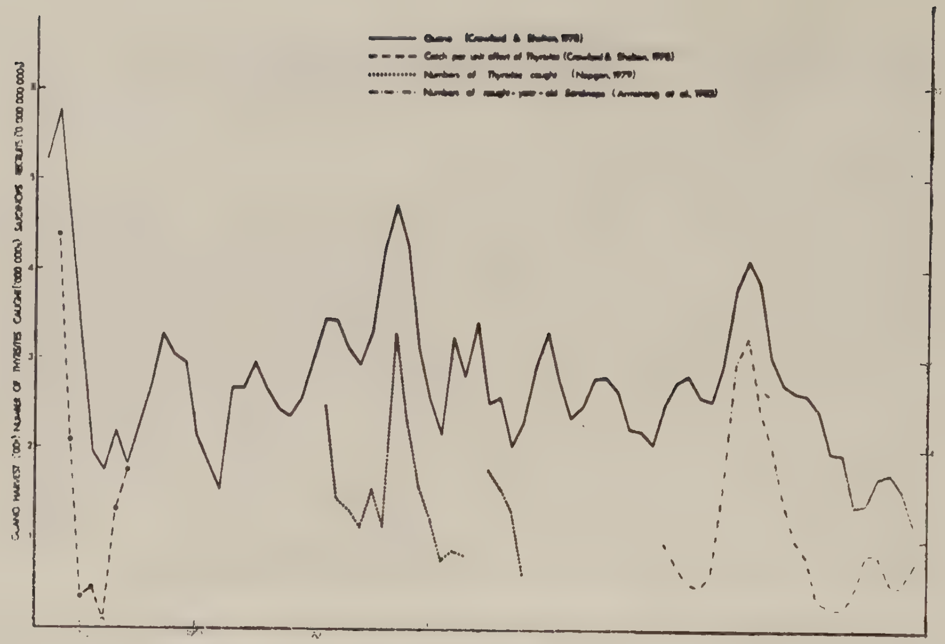

Fig. 15. Trends in the guano harvest at Lambert's Bay, and in catch rates of *Thyrsites* and in recruitment of *Sardinops* off the Western Cape, 1897-1972. Values shown are the moving averages of three years.

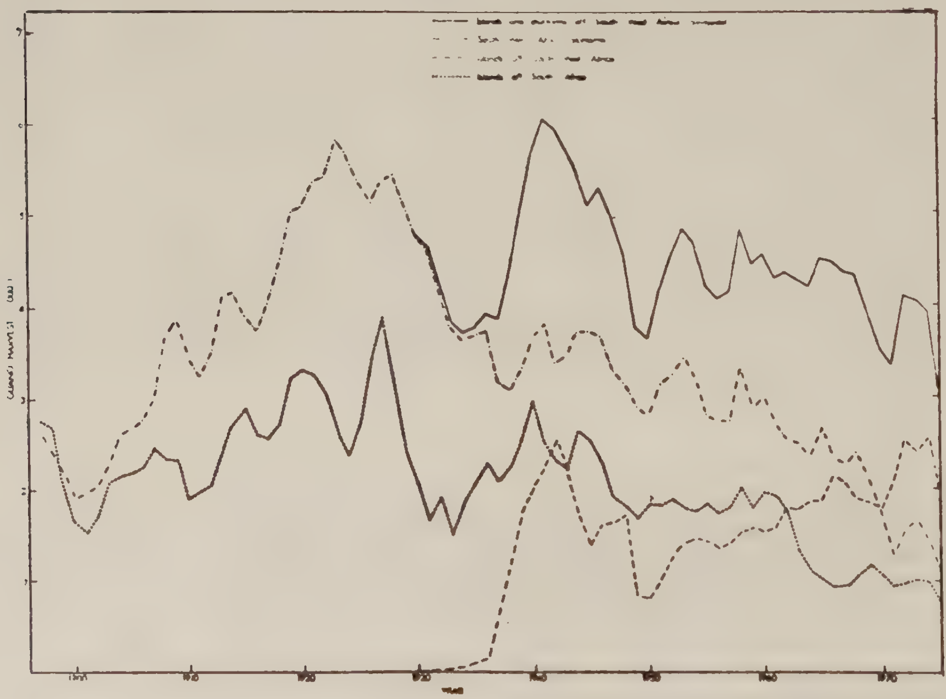

Fig. 16. Trends in the guano harvest at islands off South and South West Africa, and at guano platforms along the South West African coast, 1897-1974. Values shown are the moving averages of three years.

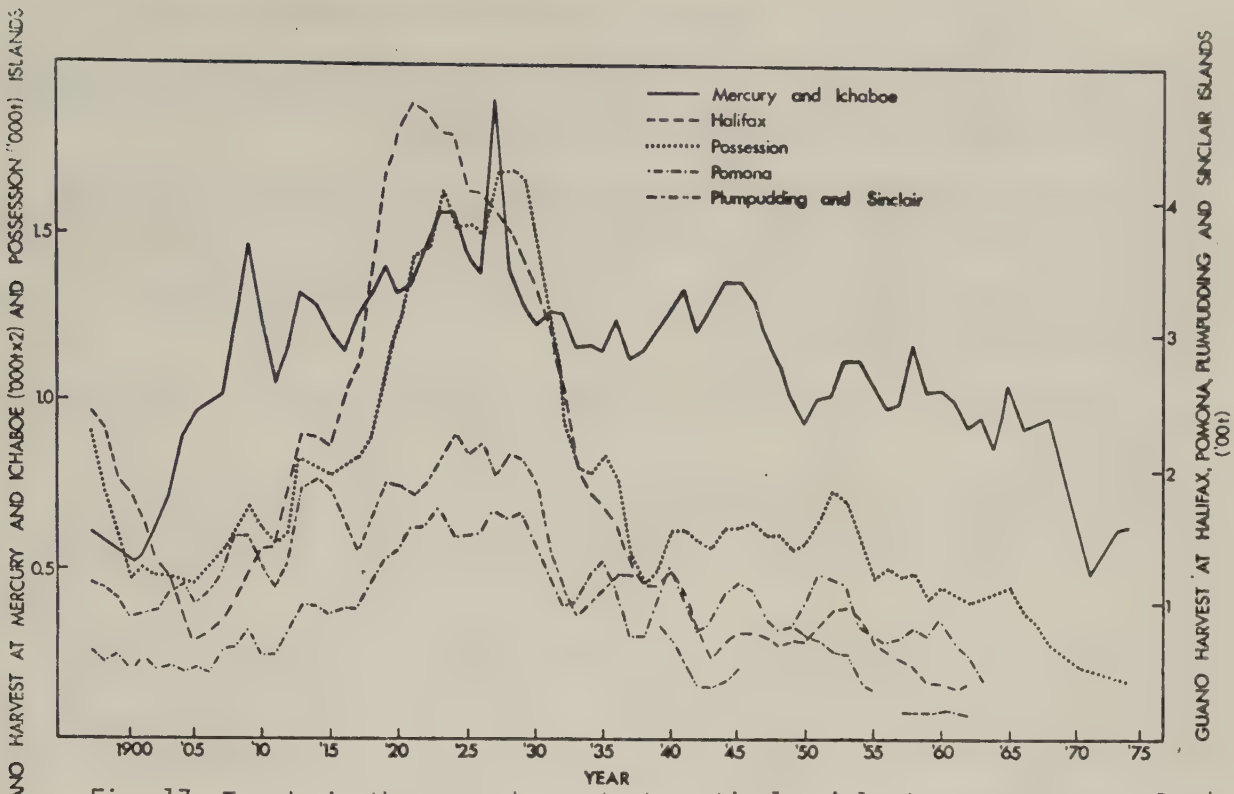

Fig. 17. Trends in the guano harvest at particular islands or groups of Islands off the South West African coast, 1897-1974. Values shown are the moving averages of three years.

Visual inspection of a correlation matrix of trends in guano harvests at islands off the southern African coast between 1897 and 1975 (during which period guano was collected by the South African government) suggests that the South West African islands form a distinct group (Fig. 18). Islands off South Africa are loosely correlated with one another and with those off South West Africa. The same technique has been applied by MacCall (1982) to examine subpopulation structure of anchovies off California.

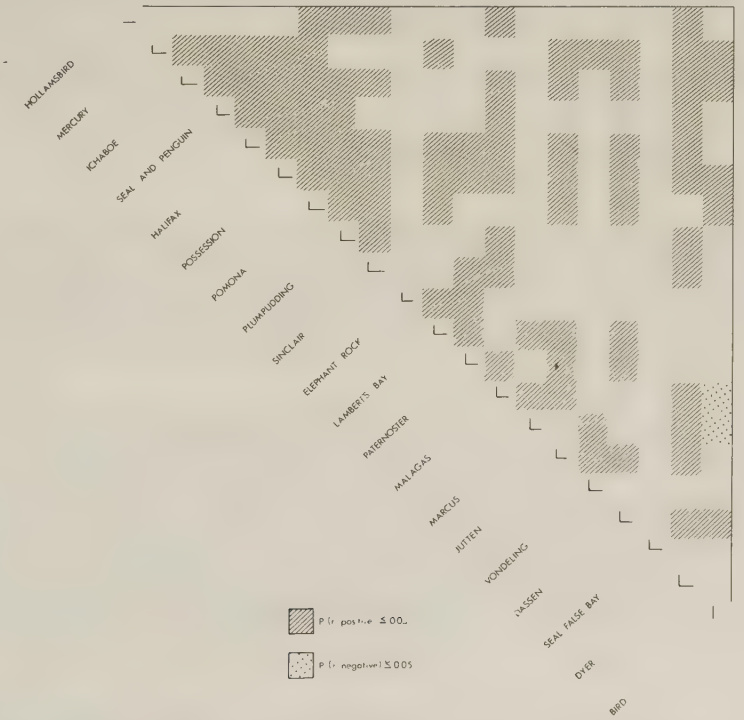
HOLLAMSBIRD
MERCURY
ICHABOE
SEAL AND PENGUIN
HALIFAX
POSSESSION
POMONA
PLUMPUDDING
SINCLAIR
ELEPHANT ROCK
LAMBERTS BAY
PATERNOSTER
MALAGAS
MARCUS
JUTTEN
VONDELING
DASSEN
SEAL FALSE BAY
DYER
BIRD
P (r positive) ≤ 0.05
P (r negative) ≤ 0.05

Fig. 18. Pattern of correlation between trends in guano harvests at islands off South West Africa. Islands are listed from north (Hollamsbird) to south (Bird) around the coast.

# CHARACTERISTICS OF VARIABILITY IN THE SOUTHERN BENGUELA SYSTEM

A number of generalized conclusions can be formulated from the foregoing concerning variability of neritic stocks in the southern Benguela system.

1. VPA indices of recruitment and biomass are in many instances validated by independent estimates of year-class strength or abundance. Either VPA and the alternative estimates are both influenced in a similar manner by availability of fish stocks, or VPA adequately described population trends. VPA is least certain for non-target species, such as roundherring off the Western Cape, and during the early stages of a fishery, especially if age information is inadequate.

2. Accepting the definition of an eruptive fluctuation provided by Caughley (1970) as a steady rise in numbers over at least two generations (cohorts in our usage) followed by a marked decline, short term eruptions of recruitment occurred in most of the fish populations examined. Exceptions were the two anchovy populations and the Western Cape chubmackerel and South West African horsemackerel stocks. Time series for anchovies extend back to 1964 off the Western Cape and 1972 off South West Africa. An increase in numbers over two cohorts was observed twice in the Western Cape, but neither population can yet be considered to have suffered a marked decline on account of the uncertainty of VPA estimates for the most recent years. There was exceptional recruitment of chubmackerel off the Western Cape in 1966 and 1967 followed by a subsequent decrease, but the 1967 cohort was less powerful than its predecessor. Year-class strength of horsemackerel off South West Africa has increased considerably in recent years. The eruptions of recruitment experienced by other populations were of short duration (two to six years) and often of sufficient magnitude to sustain the fisheries for a number of succeeding years. Examples include the horsemackerel and pilchard populations of the Western Cape.

3. Short-term recruitment failures of comparable magnitude to the eruptions have not been observed, but recruitment may decline to and continue at very depressed levels. The horsemackerel population of the Western Cape is an example.

4. A number of fish populations may experience favourable recruitment simultaneously. The pilchard stocks of the Western Cape and South West Africa both experienced recruitment eruptions during the mid 1950's. Year-class strength of horsemackerel off the Western Cape increased at the same time. Anchovies and horsemackerel off South West Africa both attained peak recruitment during the late 1970's.

5. The greatest relative increases in recruitment are often experienced by the species which has the largest biomass at the time of eruption. In particular off the Western Cape pilchards had the highest biomass in 1956 and anchovies in 1973 and off South West Africa horsemackerel during 1977-1978.

6. Some large increases in recruitment cannot be linked to any obvious environmental phenomena, for example the exceptionally strong anchovy year-class in 1973 off the Western Cape. A high upwelling index in following years (Fig. 7; Hutchings and Nelson, 1983) may have influenced formation of the 1973 cohort. However, environmental factors cannot be altogether discounted as the purseseine catch of *Lampanyctodes* in 1973 was far larger than in any other year (Table 1).

7. Some of the large-scale increases in recruitment can be plausibly related to environmental factors. Thus the exceptionally powerful 1966 cohort of chubmackerel was formed during a season in which the upwelling index was noticeably poor. Warm oceanic water is preferred by chubmackerel for spawning (Shannon, 1976). (Parrish and MacCall (1978) found that for the period 1931-1938 increased recruitment of Pacific mackerel *S. japonicus* was associated with increased seasurface temperature, reduced sealevel and reduced atmospheric pressure during the spawning season.) Off South West Africa and the Western Cape strong pilchard year-classes of the mid-1950's followed cool anomalies of seasurface temperatures, expected to be indicative of good upwelling.

8. Major perturbations in the populations of pelagic fishes appear to have occurred prior to the initiation of commercial purseseining. Guano harvests at Lambert's Bay (at the centre of the recruitment grounds for pilchards, anchovies, horsemackerel and roundherring off the Western Cape) have exhibited three major peaks since the late 1890's.

Each peak has been significantly correlated with an index of recruitment of a pelagic fish population or an index of abundance of a predator (*Thyrsites*) of pelagic fishes. Less pronounced perturbations occurred more frequently, with a mean interval of about six years.

9. Predators and commercial fisheries may compete for surplus production arising from eruptions of recruitment. The guano harvest at islands off South Africa stabilized during the early years (1943-1960) of purseseine exploitation of pelagic fishes.

10. Large fluctuations in the size of a major fish population are reflected in the combined species biomass of a region. The guano harvest at islands off South Africa declined markedly following the collapse of the pilchard stock, indicating a substantial reduction in availability of fish prey to seabird predators. Subsequent recoveries in seabird numbers have coincided with an increase in the biomass of anchovies (Crawford and Shelton, 1982).

11. Population growth of a species may be influenced by the overall biomass of fish in a system. A logistic form of growth from moderate biomass levels has been observed for the Western Cape anchovy and South West African horsemackerel stocks. Both followed severe depletions of the local pilchard populations.

12. The geographical distribution of species is sometimes related to population size. Severe collapses of the Western Cape and South West African pilchard stocks were both characterized by contractions in the range of the adult population. In each instance the reduced parent stock favoured warmer waters for spawning. A range contraction towards warmer water of the South West African pilchard stock (inferred from guano records) may have occurred prior to the initiation of commercial exploitation.

13. The southern Benguela upwelling region appears to comprise at least two subsystems. Population trends, meristic and genetic studies, tagging and a correlation matrix for guano harvests at different seabird islands suggest that fish populations off the Western Cape are discrete from those off South West Africa.

14. The same driving mechanism may influence population trends in both subsystems of the southern Benguela region. Combined guano harvests for islands off the Republic of South Africa and for those off South West Africa revealed similar trends prior to the initiation of commercial purseseine fishing. Each subsystem experienced a cool water anomaly in the mid 1950's, although that off the Western Cape preceded that off South West Africa. Large increases in recruitment of pilchards occurred in both areas in the mid 1950's.

## DISCUSSION

A number of factors may be expected to influence population variability, including intraspecific controls (e.g. Parrish and MacCall, 1978; Ricker, 1954; Csirke, 1980; Iles, 1980; MacCall, 1980b), interspecific relationships (e.g. Silliman, 1969; Radovich, 1979), environmental conditions (e.g. Smith, 1978; Kondo, 1980; MacCall, 1980a; Shuntov and Vasil'kov, 1982; Skud, 1982) and commercial exploitation (e.g. Ricker, 1963).

A preliminary investigation of phytoplankton primary production off the Western Cape has suggested that, if the primary production ration available to shoaling pelagic fishes is 18 per cent (Smith and Eppley, 1982), food may be limiting the biomass of the mixed-species pelagic resource off the Western Cape (Shannon and Henry, 1983). Intraspecific population controls as well as interspecific competition might then be expected. The pilchard has exhibited the ability to reduce its size at sexual maturity at low biomass levels (Crawford et al., 1980). Other density-dependent responses of pelagic fishes in the southern Benguela region are discussed in detail by Shelton and Armstrong (this consultation) and so are not considered further here.

In a review of the replacement of depleted fish stocks by other species Daan (1980) concluded that this phenomenon was perhaps most clearly established for the group of species that included the sardine-anchovy complex. Off both the Western Cape and South West Africa, seasons and localities for spawning by *Sardinops* and *Engraulis* are similar.

Juveniles of the two genera occur together in mixed shoals (Crawford, 1981e) and the feeding ecology of juveniles and adults is similar (King and Macleod, 1976). Collapses of pilchard stocks off the Western Cape and off South West Africa during the 1960's were followed in the 1970's by logistic-type growths of anchovy and horsemackerel populations. A logistic form of growth has also been described for the Californian anchovy *E. mordax* population (MacCall, 1980). This too followed the decline of a *Sardinops* stock, but MacCall (1980a) preferred to a hypothesis of species replacement one of a population recovery by the anchovy stock to more normal levels of abundance after a prolonged series of poor recruitment.

A second interspecific relationship is that between a predator and its prey. Hairston et al., (1960) concluded that, whereas interspecific competition must necessarily exist among populations of producers, carnivores and decomposers, herbivores are seldom limited by food, appear most often to be controlled by predators, and are therefore not likely to compete for common resources. Although more recently Caughley (1970) has shown that food may have an important influence on population trends of herbivores, the possible significance of predation for shoaling pelagic species has been highlighted by Radovich (1979). Off southern Africa clear relationships exist between indices of abundance of four dominant predators (Cape gannets, jackass penguins, Cape cormorants, snoek) and their prey. In the 1950's pilchards were the dominant forage of each predator (Davies, 1955; 1956; Rand, 1959b; 1960a; 1960b; Matthews, 1961), but following depletions of the pilchard resources the importance of anchovies in their diets increased greatly (Nepgen, 1979a; Crawford and Shelton, 1982; Furness and Cooper, 1982). For snoek at least the change of prey occurred immediately after the collapse of the Western Cape pilchard population (Nepgen, 1979b). Should predators increase following the eruption of a major prey population, return of the prey to more normal levels of abundance and a consequent diversification in the diet of predators could result in an increased natural mortality rate for all prey species until the predators themselves again come into equilibrium with their forage. In this manner replacement of one pelagic species by another might be delayed.

Environmental factors are a frequently cited cause of variability in pelagic fish populations (e.g. Csirke, 1980; Kondo, 1980; MacCall, 1980a; Saville, 1980). Boyd (1979) found a significant correlation between variability of seasurface temperatures and recruitment. Recruitment was favoured by reasonably constant temperatures and it was argued that feeding success of anchovy larvae was greater in stable conditions (Boyd, 1979). The present paper has shown that a number of eruptions of recruitment for neritic stocks in the southern Benguela system can be plausibly linked to environmental anomalies.

The similarity between biomass trends off South Africa and off South West Africa, as inferred from guano harvests, and simultaneous eruptions in recruitment, sometimes over a wide geographic region, may be evidence that environmental phenomena operating over a scale of hundreds of km are more important than localised events in determining recruitment in the southern Benguela system. At this scale the use of satellite imagery for environmental monitoring as an aid to fisheries management may be useful (e.g. Shannon and Anderson, 1982). Skud (1982) cites instances in which changes in abundance of dominant and subordinate species of fish were respectively positively and negatively correlated with environmental factors that improved survival. In Californian waters a number of species experienced poor recruitment during the late 1940's and early 1950's (MacCall, 1980a). Off southern Africa year-class strength for two species improved markedly on at least two occasions. In each instance the largest relative increase in recruitment was experienced by the stock having the largest biomass.

The Japanese sardine *S. melanosticta* fishery recently increased dramatically after a period of poor catches lasting about 30 years (Kondo, 1980). Biomass of the Californian anchovy was high in the early 1940's and again in the mid 1960's (MacCall, 1980a). Off the Western Cape there may have been three large eruptions of recruitment since the late 1890's at intervals of approximately 30 years. Guano indices suggest that smaller perturbations also occurred at intervals of about six years. Such a happening would have ensured the formation of at least one strong year-class for each generation of pilchards. Anchovies, with their shorter lifespan (Crawford et al., 1978), are likely to be adapted to a shorter cycle and estimates of recruitment indicate an alternation of good and not-so-good year-classes (Figs. 8 and 11).

Moderate fishing of stocks that prior to exploitation include a large number of age groups can cause a major reduction in population size (Ricker, 1963). Off southern Africa intensive fishing of the multispecies pelagic stocks with smallmeshed nets has led to a current dominance of species having a short generation time (Newman and Crawford, 1980). Species characterised by a greater longevity, such as pilchards, horsemackerel and chubmackerel, now contribute little to the landings and a high fishing mortality on the younger ages maintains the parent populations at a low level (Newman and Crawford, 1980). Reductions in the geographic range of egg production, as have been observed for both pilchard populations, could adversely affect the probability of larvae encountering favourable environmental conditions, increase chances of recruitment failure (Saville, 1980) and decrease likelihood of favourable eruptions (Newman and Crawford, 1980).

In conclusion it appears that variability of the multispecies neritic complex in the southern Benguela system is to some extent biologically controlled, especially at the biomass levels. However, environmental factors and exploitation patterns are likely to be of even greater importance, the former in influencing largescale eruptions of recruitment and the latter in determining species composition. Eruptions of recruitment are naturally infrequent, and frequency of occurrence may be further reduced by changes in age structure and geographic distribution of species brought about by fishing.

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*SOUTH WEST ATLANTIC - ATLANTICO SUDOCCIDENTAL*

# BIOLOGIA Y DISPONIBILIDAD DE SARDINA (*Sardinella brasiliensis*, Steindachner, 1879) EN LA COSTA SUDESTE DEL BRASIL

Compilado por

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## Summary

The results obtained from the studies of the biology and stock assessment of *Sardinella brasiliensis* that inhabit the littoral zone of southeast Brasil (22°-28°S) are presented, as provided by the Permanent Group for the Studies of Sardines.

Related to reproduction, the analysis of frequencies of maturity stages and gonadal development indices show that peak spawning occurs in summer, particularly in the months of January and February. The average size at onset of sexual maturity was estimated to be 16.7 cm and the average fecundity was 23,000 eggs per adult female.

Age determination for the study of growth, obtained by reading otolith rings, showed that the catch comprises principally of individuals with two or three classes of rings, in which the most frequent group has four rings and a corresponding size of about 18 cm. The value of the growth constant "k" is also discussed. Total landings of *S. brasiliensis* have diminished drastically in recent years, passing through a maximum of 228,000 tons in 1973 to 90,000 tons in 1982. The MSY calculated by the application of the general production model was 170,000 tons.

Natural mortality was estimated at 0.74 using the method of Pauly (1980) and then this was applied to preliminary cohort analyses. The results of these analyses are also discussed.

Evaluations of total biomass derived from hydroacoustic studies made during the period 1974-1980 yielded values ranging from 142,000 to 414,000 tons.

The available information for stock diagnoses do not appear to explain conclusively the reasons that have provoked the decline in catches. Various hypotheses about this topic are discussed.

## INTRODUCCION

Entre las especies pelágicas de importancia económica del Brasil, la sardina es aquella que está sujeta al mayor esfuerzo de pesca por parte de la flota comercial. La sardina se captura en gran cantidad en el área comprendida entre los 22°S y 28°S (Cabo de São Tomé a Cabo Santa Marta Grande), a una profundiad máxima de operación de aproximadamente 70 m. (Fig. 1).

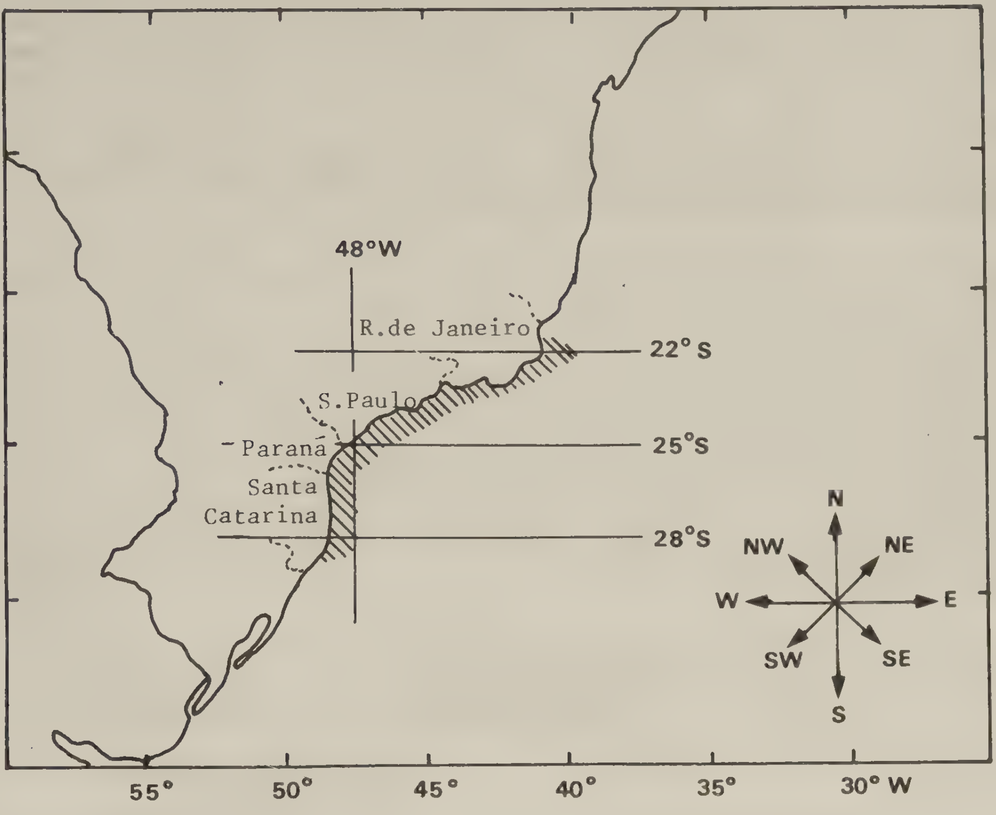

Fig.1 - Area de pesca de la sardina (*Sardinella brasiliensis*)

Existe un gran volumen de datos y un gran número de trabajos sobre esta especie, iniciados en 1950. En vista de la importancia de este recurso la SUDEPE (Superintendencia del Desarrollo de la Pesca), promueve, desde 1974, reuniones anuales del Grupo Permanente de Estudios sobre la Sardina - GPE (*) -, con la finalidad de actualizar las informaciones disponibles sobre la situación del recurso y recomendar medidas de administración.

En 1979, durante la reunión del Grupo Permanente, se constató que los estudios eran dispersos y existían diferencias en la metodología de los muestreos y en los criterios de obtención de datos por lo cual no era posible tener un cuadro sinóptico satisfactorio de los conocimientos de la especie. Por este motivo se creó un Programa de Estudios Biológicos sobre Sardina (PIEBS) que está siendo llevado a cabo por investigadores del GPE y que tiene por objetivo el seguimiento continuo de la población de sardina, los cambios en su estructura y las variaciones de los parámetros biológicos. Este programa de estudios analiza las informaciones de caracter biológico y las relaciona con los datos de captura y esfuerzo de pesca con la finalidad de evaluar la situación del recurso y contribuir a una adecuada administración pesquera.

Durante el 2º Encuentro del Grupo de Trabajo y Entrenamiento sobre Evaluación de Stocks (GTT) de 1981 promovido por la FAO, se revisaron los trabajos existentes sobre la especie y se analizaron los más recientes datos disponibles, llegándose a hacer una estimacion del nivel de explotación de la población y el estado de la pesca (PDP/SUDEPE, 1981a).

La presente contribución pretende documentar los últimos resultados sobre biología y evaluación de stock de sardina según fueron presentados en la última reunión del GPE y en el GTT.

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(*) El Grupo Permanente de Estudios sobre la Sardina (GPE) está constituido por científicos de la SUDEPE (Ministerio de Agricultura), Instituto de Pesca (Secretaría de Agricultura del Estado de San Pablo) e Instituto Oceanográfico (Universidad de San Pablo).

## BIOLOGIA

### Estructura de la especie

Existen evidencias de que la especie no se comporta homogéneamente a lo largo de su área de explotación en la costa brasilera.

Estudios basados en el análisis de la distribución de frecuencia de tallas (Richardson et al., 1959; Richardson y Sadowski, 1960) y del período y lugar del desove (Rossi-Wongtschowski, 1977; Projecto Megalosar, 1980) sugieren la existencia de dos grupos diferenciados: uno entre 22° - 25°S y otro entre 26° - 28°S con épocas de desove diferentes. Los jóvenes de cada uno de estos grupos penetrarían en la región estuarino-lagunar de Cananéia (25° 01'S) en épocas distintas: el grupo septentrional en abril y el meridional en octubre saliendo en mayo (Richardson y Sadowski, 1960). Algunos estudios bioquímicos y morfológicos contribuyen a apoyar esta observación.

En estudios bioquímicos se constató que los patrones electroforéticos de las proteínas totales del cristalino de sardina pueden ser usadas como marcas naturales para el estudio de la estructura de la especie (Vazzoler y Ngan, 1976).

Por otra parte, los datos de proporciones corporales y carácteres merísticos de 3351 ejemplares capturados entre 22° - 28°S en el período de 1970 a 1974 (Rossi-Wongtschowski, 1978) analizados aisladamente no permiten caracterizar los individuos provenientes de cada grupo debido a la gran variabilidad individual causada por la enorme plasticidad de la especie, asociada a los movimientos de los individuos en el sentido N-S e viceversa, resultando en un mosaico. Sin embargo, el análisis de las variaciones del número de branquispinas del primer arco branquial izquierdo permitieron sustentar algunas hipótesis sobre la existencia de estos grupos.

En relación a la morfología de los otolitos se constataron diferencias estadísticamente significativas en las relaciones entre la longitud del rostro y antirostro; y en los pesos de los otolitos con la talla de los ejemplares (Rossi-Wongtschowski et al., 1982). El análisis de las características de los otolitos (tipo de núcleo y forma) de los ejemplares capturados en diferentes áreas y épocas del año sugiere la existencia de mezcla de los grupos entre sí.

Están aún en fase de estudio los análisis del tipo bioquímico y las proporciones corporales como medio para caracterizar morfológicamente los posibles grupos (Projecto Megalosar, 1980, 1981).

### Estructura de la población:

Proporción Sexual: generalmente existe una mayor frecuencia de hembras que de machos durante el transcurso del año, con excepción de la época del desove (verano), cuando las frecuencias entre ambos sexos tienden a igualarse (Matsuura, 1977; PDP/SUDEPE, 1982 b).

Composición por tamaños: Se observa heterogeneidad en la composición de los individuos por clase de talla a lo largo del área de distribución (Projecto Megalosar, 1980); la tabla 1 muestra la amplitud de talla y las clases más frecuentes en la pesquería comercial.

Tabla 1.- Amplitud de talla (mm) y clases de talla más frecuentes de sardinas provenientes de pesquerías comerciales, por región.

| región | amplitud (mm) | clase más frecuente (mm) |
|---|---|---|
| 22º - 23ºS (Cabo Frío) | 150-260 | 240;250 |
| 23º - 24ºS (Angra dos Reis; Santos) | 130-240 | 200 |
| 25º - 26ºS (Cananéia; Paranaguá) | 170-210 | 190 |
| 26º - 28ºS (Itajaí; Florianópolis) | 120-230 | 180 |

Considerando también los datos obtenidos de la pesca artesanal, la cual incluye ejemplares con tallas inferiores a 170 mm, se verifica que el reclutamiento a la pesca ocurre principalmente en los meses de agosto y septiembre.

La mayor frecuencia de individuos pequeños se observa en la región estuarino-lagunar entre los 25º y 26ºS.

Composición por clases de edad: la pesca incide principalmente sobre dos o tres clases de edad, encontrándose una composición diferencial a lo largo del área: en la región entre 22º-23ºS predominan dos individuos más viejos y en la región 25º-26ºS los más jóvenes (Projecto Megalosar, 1981).

Se observó que la especie comienza a ser capturada cuando posee 3 anillos en sus otolitos, permaneciendo disponible para la pesca durante un período correspondiente a la formación de 3 o 4 anillos más (PDP/SUDEPE, 1982 b).

## Reproducción

Madurez gonadal: Estudios histológicos de los ovarios permitieron establecer las características del desarrollo gonadal y una escala de madurez adecuada (ISAAC-NAHUM *et al.*, 1983).

Considerando las características macro y microscópicas de las gónadas de hembras adultas se verifica que la mayor parte de los individuos permanece en fase de reposo gonadal de abril a septiembre, madurando en seguida rápidamente; el estadio de pre-desove es alcanzado en noviembre por los individuos de Río de Janeiro y posteriormente por aquellos de San Pablo y Santa Catarina, lo cual puede sugerir que el desove se inicia más tempranamente en la región Norte. (Fig. 2).

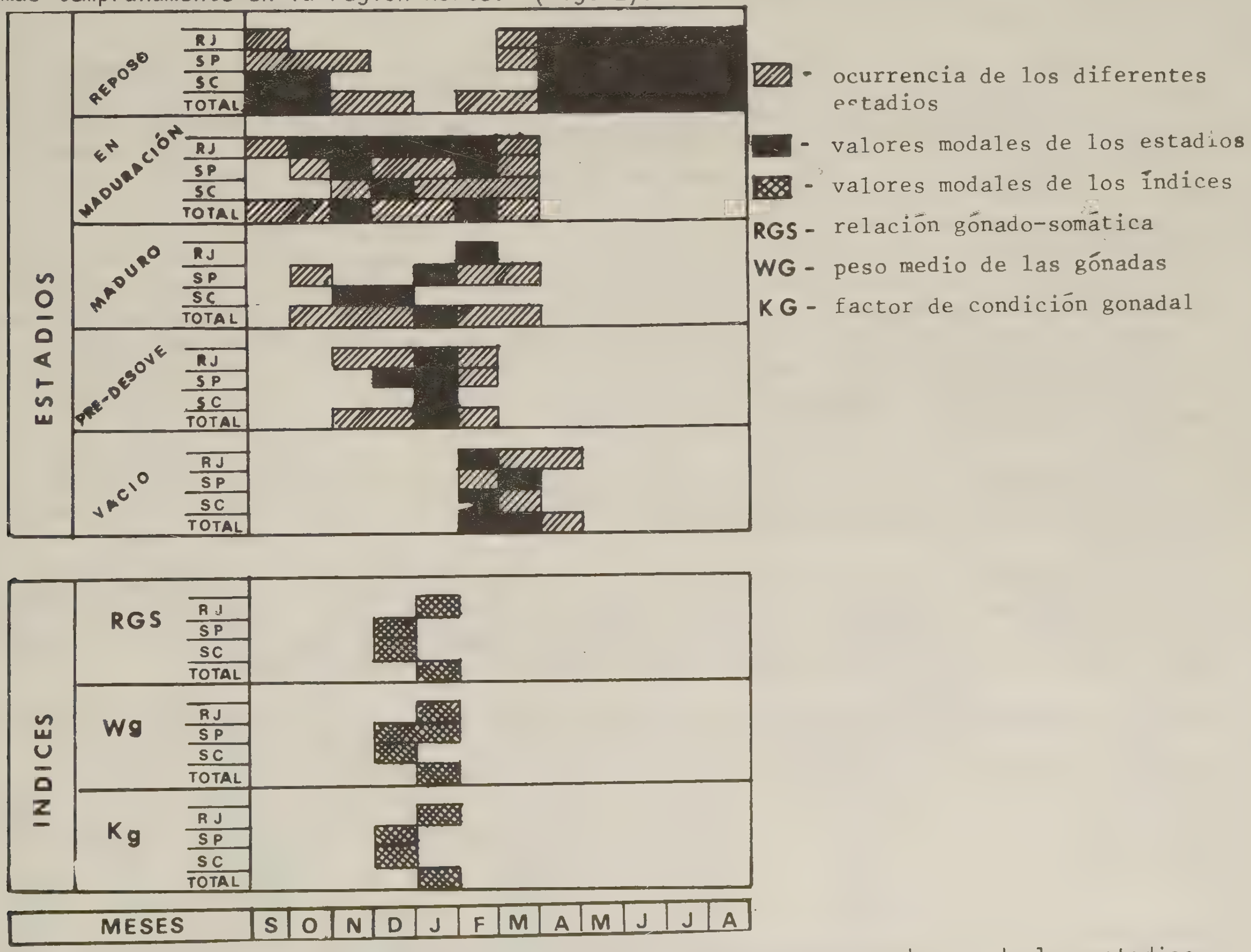

Fig. 2.- Cuadro comparativo señalando los meses en que aparecen cada uno de los estadios de madurez y también sus mayores frecuencias así como los valores modales de los índices de madurez para los Estados de Río de Janeiro, San Pablo y Santa Catarina y para el área global (período Septiembre 1981 - Agosto 1982).

En el análisis de la relación gónado-somática, peso y factor de condición gonadales se notó que estos valores aumentan con el tamaño del pez, o sea, individuos mayores poseen gónadas mayores y por tanto índices más altos que los ejemplares menores; sin embargo, parece que no hay diferencias acentuadas en relación con la época de desove entre las diferentes clases de talla, significando que todos los peces desovan aproximadamente en el mismo período (PDP/SUDEPE, 1982 b). Los valores modales de estos indicadores de desarrollo gonadal ocurren entre los meses de diciembre y enero (Fig. 2).

Fecundidad.- La fecundidad real media, obtenida para 16 hembras según el método de Ciechomski et al.,(1973), y considerando apenas los ovocitos que pertenecen a la última moda de la distribución de frecuencia de sus diámetros, fue estimada en 23 000 ovocitos por hembra (PDP/SUDEPE, 1982 b).

Talla media del inicio de la primera madurez gonadal.- El valor encontrado para ambos sexos y para el area global fue 167 mm (PDP/SUDEPE, 1982 b).

Tipo de desove.- A pesar de que las curvas de distribución de diámetros de ovocitos intraováricos se presentan bimodales, el comportamiento de estas curvas muestran un patrón de desove total, una vez que los ovocitos representados por la última moda crecen, aumentando su diámetro, mientras que los otros, menos diferenciados, permanecen estables. Este hecho, reforzado por la presencia de ovocitos que pertenecen a la primera moda en los ovarios vacios, hace pensar que estas células estarían destinadas a ser reabsorbidas por el ovario y no a evolucionar y ser eliminadas después de la liberación del primer lote (PDP/SUDEPE, 1982 b).

Epoca y área de desove.- Rossi-Wongtschowski (1977) y Projecto Megalosar (1980), sugieren la existencia de dos áreas principales de desove: una entre 22º - 25ºS, de octubre a junio (con picos en diciembre-enero y marzo-abril), y otra entre 26º - 28ºS, de diciembre a enero (con pico en enero).

Sin embargo hemos encontrado grandes variaciones de año para año, probablemente debido a cambios en las condiciones ambientales. Los resultados más recientes indican que hay reproducción en toda el área de distribución y un período de desove más restricto entre noviembre y abril con picos en enero-febrero (PDP/SUDEPE, 1982 b). Según Matsuura (1977) el desove ocurre con mayor intensidad entre las isobatas de 51 a 100 m.

### Crecimiento

Los estudios sobre crecimiento de *S. brasiliensis* en el Brasil no siempre abarcaron toda el área de mayor densidad de la distribución de la especie. Estos han sido realizados a través del análisis de las distribuciones de frecuencia de tallas (Richardson et al., 1959; Santos y Fratzen, 1965; Matsuura, 1977; Rijavec et al., 1977), lectura de anillos de escamas (Richardson et al., 1959) y otolítos (Vazzoler, et al., 1982a, 1982b; Rossi-Wongtschowski et al., 1982; PDP/SUDEPE, 1982 b).

Fue constatado que los otolitos son más adecuados para la lectura que las escamas (Rossi-Wongtschowski et al., 1982). y se comprobó la periodicidad y época de formación de los anillos de crecimiento (Vazzoler et al., 1982a).

La longevidad de los individuos defiere a lo largo del área de distribución: se encontraron peces hasta 7 años en las regiones entre los 22º-25ºS, hasta 6 años entre 26º - 28ºS, y en la de 25º - 26ºS (región estuarino-lagunar) solamente individuos hasta 4 años (Rossi-Wongtschowski et al., 1982; Vazzoler et al., 1982a e b; PDP/SUDEPE, 1982 b).

Tabla 2.- Parámetros de crecimiento de sardina obtenidos en los varios trabajos científicos

| región | $L_\infty$ (mm) | K | $t_0$ | $W_\infty$ (g) | Autores |
|---|---|---|---|---|---|
| 22º-23ºS | 23,5 | 0,54 | -0,24 | 112,0 | Vazzoler et al., 1982 b |
| 23º-25ºS | 24,3 | 0,50 | 0,00 | | Santos y Fratzen, 1965 |
| | 24,4 | 0,44 | 0,00 | | Matsuura, 1977 |
| | 33,5 | 0,87 | 0,00 | | Rijavec et al., 1977 |
| | 22,4 | 0,46 | -0,75 | 100,8 | Vazzoler et al., 1982 b |
| 25º-26ºS | 17,7 | 0,39 | -0,74 | 46,1 | Vazzoler et al., 1982 b |
| 26º-28ºS | 22,5 | 0,37 | -1,02 | 88,9 | Vazzoler et al., 1982 b |

Comparando los resultados encontrados para el área 23º-25ºS, se verifican diferencias entre los parámetros indicados (Fig. 3), las cuales podrían ser debidas a las diferentes metodologías empleadas.

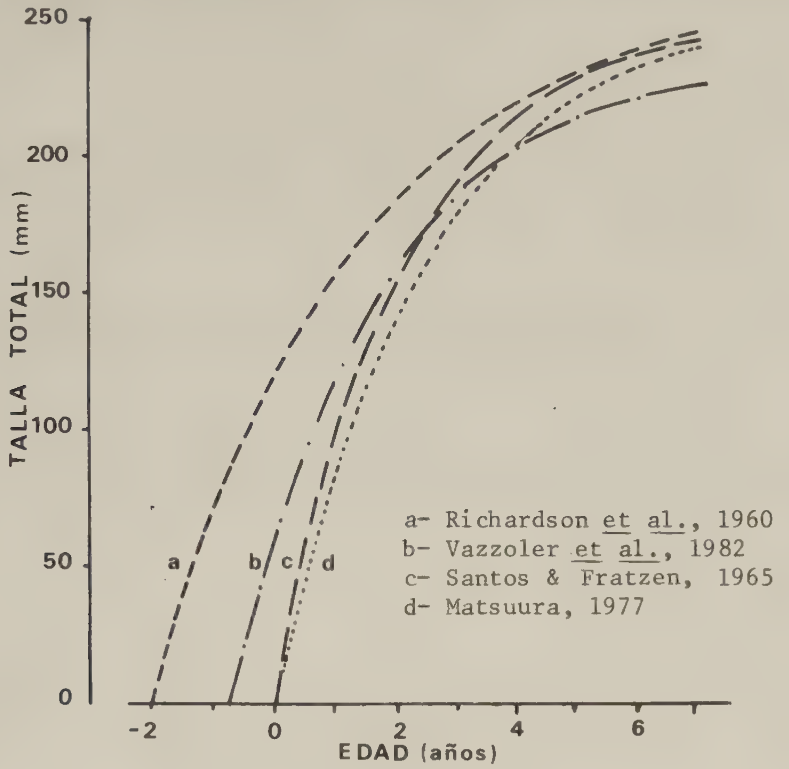

Fig. 3 - Comparación gráfica de las curvas de crecimiento de S. brasiliensis en la región entre 23º-25ºS obtenidos por varios autores (adaptado de Vazzoler et al., 1982 b).

En los resultados obtenidos por Vazzoler et al. (1982 b), se observaron patrones de crecimiento distintos según sea el área considerada (Fig. 4); los peces de la región

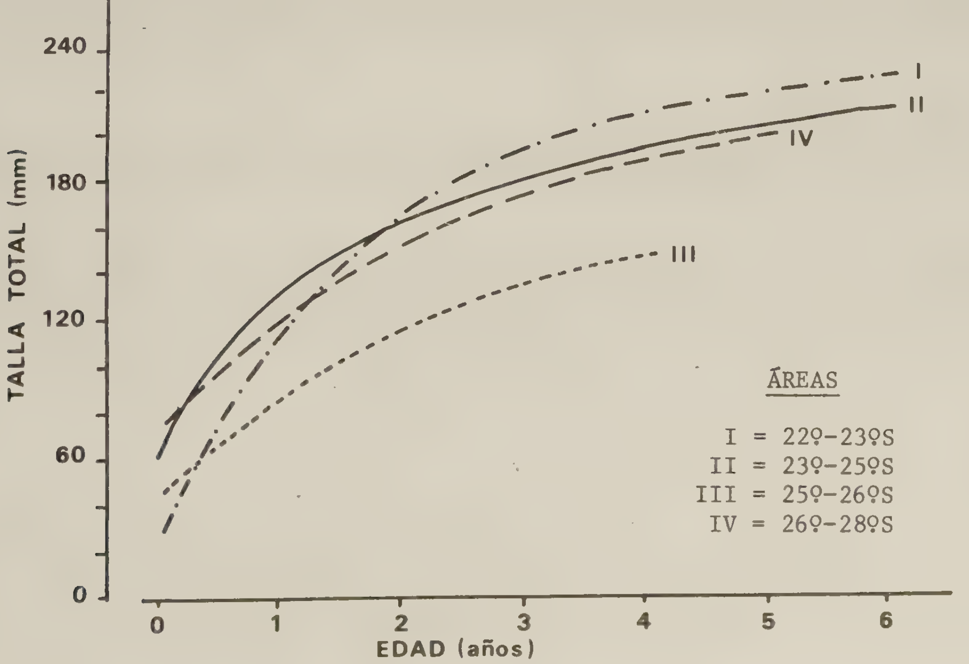

Fig. 4 - Comparación gráfica de las curvas de crecimiento en talla de S. brasiliensis para las cuatro regiones estudiadas por Vazzoler et al.(1982 b).

estuarino-lagunar presentan crecimiento menor que los de mar abierto y entre estos últimos existe una variación clinal en el sentido Norte-Sur, siendo que los ejemplares que habitan la región más al Norte presentan crecimiento más intenso tanto en talla como en peso.

## EVALUACION DE STOCK

### Caracterización de la flota y de la pesquería

La pesca de sardina, inicialmente artesanal, comenzó a desarrollarse en términos industriales en la década del 1940 en los Estados de Río de Janeiro y San Pablo con la mecanización de la flota, y más recientemente en la década del 1960 en el Estado de Santa Catarina (PDP/SUDEPE, 1981a).

Existen actualmente un total de 378 embarcaciones conocidas con el nombre de "traineiras": 88 registradas en el Estado de Santa Catarina, 65 en San Pablo y 225 en Río de Janeiro. La tabla 3 muestra los promedios de las principales características físicas de estas unidades.

Tabla 3.- Valores promedio de las principales características físicas de las embarcaciones que operan en la pesquería de sardina, por región

| características físicas del barco | SC | SP | RJ |
|---|---|---|---|
| Eslora (m) | 20,8 | 19,6 | 14,1 |
| Capacidad de la bodega ($m^3$) | 51,8 | 36,6 | 26,1 |
| Arqueo bruto (ton.) | 66,5 | 51,7 | 24,6 |
| Edad (años) | 10 | 19 | 19 |
| Número de barcos | 88 | 65 | 225 |

Podemos constatar que los barcos de Santa Catarina (SC) son mayores y más modernos que los de San Pabo (SP) y Río de Janeiro (RJ) (PDP/SUDEPE, 1982a), lo que probablemente determina diferencias en el poder de pesca entre estas flotas.

La pesca es realizada durante las noches sin luna; los cardúmenes son localizados por métodos visuales por el proero (vigía) y son posteriormente cercados con una red de cerco que mide cerca de 500-675 m de largo y 40-76 m de altura (Wiefels y Jablonski, 1979). A continuación, los peces son cargados a cubierta con pequeños sacos. Toda la operación dura aproximadamente 3 horas.

### Desembarques de sardina

La disponibilidad de sardina para la pesca difiere de año para año y particularmente de mes a mes, a pesar de no obedecer a un patrón definido de comportamiento (PDP/SUDEPE, 1981a).

Considerando los datos disponibles desde 1964, los desembarques de sardina presentan valores ascendentes hasta 1973, cuando la producción alcanzó su máximo de 228 037 ton.; a partir de entonces se observa una tendencia de disminución hasta 1976 (105 053 ton.), manteniéndose estable en los cuatro años siguientes alrededor de las 145 000 ton. En los últimos dos años las capturas disminuyeron llegando hasta el valor mínimo de 90 000 ton. en 1982 (Fig. 5).

### Esfuerzo y abundancia

Analizando la tendencia del esfuerzo aplicado a la especie se nota que a pesar del aumento de la intensidad de pesca, en el período 1964-1973, el índice de abundancia (captura/lance) se mantuvo estable; en los últimos años, después de una brusca caída del esfuerzo (entre 73 y 78), este se mantuvo en el mismo nivel, mientras que la abundancia que aumenta inicialmente, comienza a disminuir a partir de 1978 (Fig. 5).

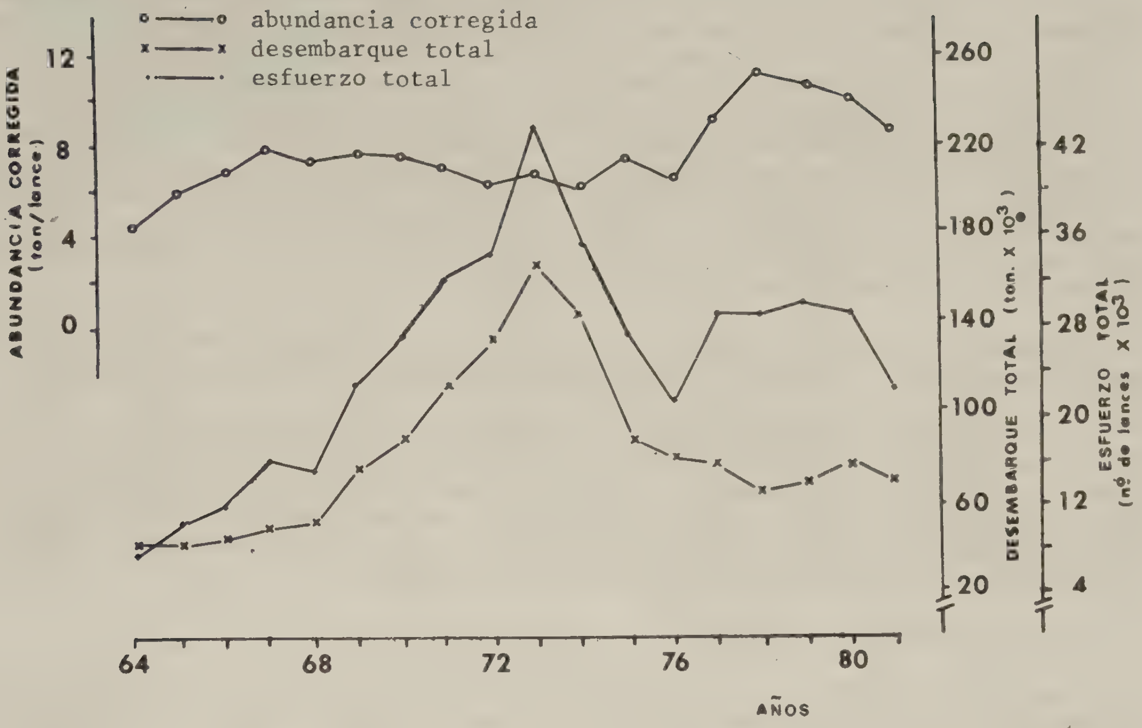

Fig. 5 - Desembarque total (ton), esfuerzo total estimado (nº de lances) y índice de abundancia de San Pablo (corregido), para *S. brasiliensis* en el período 1964-1981.

La interpretación de estos datos parece incierta, debiéndose resaltar que la medida de esfuerzo empleada puede no ser adecuada para estimar la densidad promedio real de la población. Esto por la modalidad de la pesquería, en que sólo se realiza el lance cuando el cardumen ha sido avistado, por tanto los datos de captura/lance miden más las variaciones en el tamaño del cardumen que la abundancia del recurso (ACMRR, 1976).

Por otro lado, los datos de "número de viajes" tampoco serían satisfactorios ya que, debido a los altos costos operacionales de la flota, especialmente en los últimos años, se nota una tendencia a solo realizar viajes cuando hay certeza de la disponibilidad de cardúmenes en determinada área.

Por otro lado, los datos sobre "horas de búsqueda" no parecen confiables, siendo necesario en el presente encontrar una forma de integrar las diversas medidas de esfuerzo para poder determinar con exactitud las oscilaciones de la abundancia.

## Consideraciones sobre la crisis de la producción en el período 1981-1982

Existe una gran preocupación por parte de los administradores y empresarios de la pesca de sardina con respecto a la disminución brusca de las capturas en los últimos dos años.

Para tratar de explicar esta disminución se formularon las siguientes hipótesis:

1º) disminución del poder de pesca o del esfuerzo debido a la salida de algunas embarcaciones grandes que fueron transferidas a la pesquería de atunes, o que se retiraron debido a la inviabilidad económica de la pesca.

2º) no disponibilidad del recurso en las áreas de pesca accesibles a la flota comercial.

3º) disminución de la biomasa de sardina por fallas de reclutamiento u otras causas similares.

En relación con la primera hipótesis cabe mencionar que se están fomentando mejoras en los equipamientos de los barcos, principalmente para la adquisición de instrumentos de búsqueda y localización de cardúmenes, de manera de aumentar la productividad de cada viaje. Por otro lado se trató de estimar la capacidad real de pesca de la flota operativa a la fecha, con la finalidad de determinar el potencial de producción máxima de la mísma. De esta manera, considerando el año en que se hicieron las mayores capturas (1973) se calculó el índice de abundancia máxima en la forma captura/barco, y sabiendo el número de barcos que efectivamente operaron en la pesca durante el año de 1982, se estimó así un potencial capturable de cerca de 160 000 ton/año. Este valor debe ser entendido apenas como un indicador de potencial de pesca, si la abundancia de sardina fuese igual a la ocurrida en 1973, y en la medida que la relación viaje/barco se mantenga dentro de los valores medios observados en los años anteriores.

Podemos sin embargo concluir que la flota actual a pesar de sus limitaciones técnicas, parece capacitada a capturar un total bastante próximo al MSY calculado para el recurso.

Las otras hipótesis permanecen en el campo de la especulación, ya que todavía no existe un seguimiento sistemático de las fluctuaciones de la biomasa del stock desovante y del reclutamiento, ni tampoco de las variaciones de los parámetros ambientales. Con todo, se ha observado el estrechamiento del área de mayor densidad de la especie, y en los últimos años la pesca en los extremos Norte y Sur ha bajado sensiblemente, hecho que podría indicar una disminución en el tamaño del stock.

## Modelo de producción general

Los datos estadísticos de la pesca de sardina se obtienen por muestreos ya que no es posible cubrir el total de operaciones efectuadas. Conociendo el monto total de los desembarques y la CPUE estimada para una muestra estadísticamente significativa de la flota, obtenemos el esfuerzo de pesca total estimado para cada período.

Los datos de esfuerzo del período 1964-1973 fueran corregidos según Matsuura (1981) de acuerdo con el aumento del promedio del arqueo bruto de los barcos durante esos años (Tabla 4).

Usando el "lance" como medida de esfuerzo y la CPUE estimada sólo para la flota del Estado de San Pablo (por ser estas estadísticas más confiables), se aplica el modelo de Fox (1970) para el cálculo del rendimiento máximo sostenible (MSY) para el período 1969-1981.

Los parámetros fueron estimados a través de una regresión funcional debido a las características de las variables usadas (Ricker, 1975) obteniéndose los siguientes valores y ecuaciones (Fig. 6):

$$\mathrm{MSY} = 169\ 923 \text{ ton.}$$

$$F_{opt} = 30\ 525 \text{ lances}$$

$$\ln \bar{U} = 2.7174 - 3.2772 - 10^{-5}\ \bar{f}$$

$$Ye = \bar{f}\ .\ e^{(2.7174-3.2773.10^{-5}\ \bar{f})}$$

$$r = 0.76$$

Tabla 4.- Datos de desembarque total (ton), índice de abundancia para S. Pablo (ton/lance), factor de corrección del esfuerzo (Matsuura, 1981), índice de abundancia corregido, esfuerzo total estimado después de la corrección, y esfuerzo de equilibrio para el período 1964-1981

| AÑO | DESEMBARQUE TOTAL NO-SP-PR-SC (t) Y | CAPTURA/LANCE SP $\bar{J}$ | FACTOR DE CORRECION DE ESFUERZO | CAPTURA/LANCE SP CORREGIDO J | ESFUERZO TOTAL ESTIMADO- f (Y. ) | T (2 años) |
|---|---|---|---|---|---|---|
| 1964 | 38.772 | 2,7 | 0,61 | 4,4 | 0.012 | - |
| 1965 | 50.777 | 3,6 | 0,61 | 5,9 | 8.606 | - |
| 1966 | 59.553 | 4,0 | 0,63 | 6,7 | 8.009 | - |
| 1967 | 80.413 | 5,0 | 0,63 | 7,9 | 10.179 | - |
| 1968 | 76.221 | 4,8 | 0,65 | 7,4 | 10.300 | - |
| 1969 | 113.768 | 5,4 | 0,70 | 7,7 | 14.775 | - |
| 1970 | 135.400 | 5,9 | 0,78 | 7,6 | 17.816 | 16.296 |
| 1971 | 161.027 | 6,2 | 0,87 | 7,1 | 22.680 | 20.248 |
| 1972 | 170.706 | 6,0 | 0,93 | 6,4 | 26.673 | 24.677 |
| 1973 | 228.037 | 6,6 | 0,97 | 6,8 | 33.535 | 30.104 |
| 1974 | 177.089 | 6,2 | 1,00 | 6,2 | 28.563 | 31.049 |
| 1975 | 136.104 | 7,6 | 1,00 | 7,6 | 27.908 | 23.236 |
| 1976 | 105.276 | 6,5 | 1,00 | 6,5 | 16.196 | 17.052 |
| 1977 | 145.576 | 9,3 | 1,00 | 9,3 | 15.653 | 15.925 |
| 1978 | 144.685 | 11,3 | 1,00 | 11,3 | 12.804 | 14.229 |
| 1979 | 149.542 | 10,8 | 1,00 | 10,8 | 13.846 | 13.325 |
| 1980 | 146.277 | 9,2 | 1,00 | 9,2 | 15.900 | 14.873 |
| 1981 | 111.967 | 8,6 | 1,00 | 8,6 | 13.019 | 14.460 |

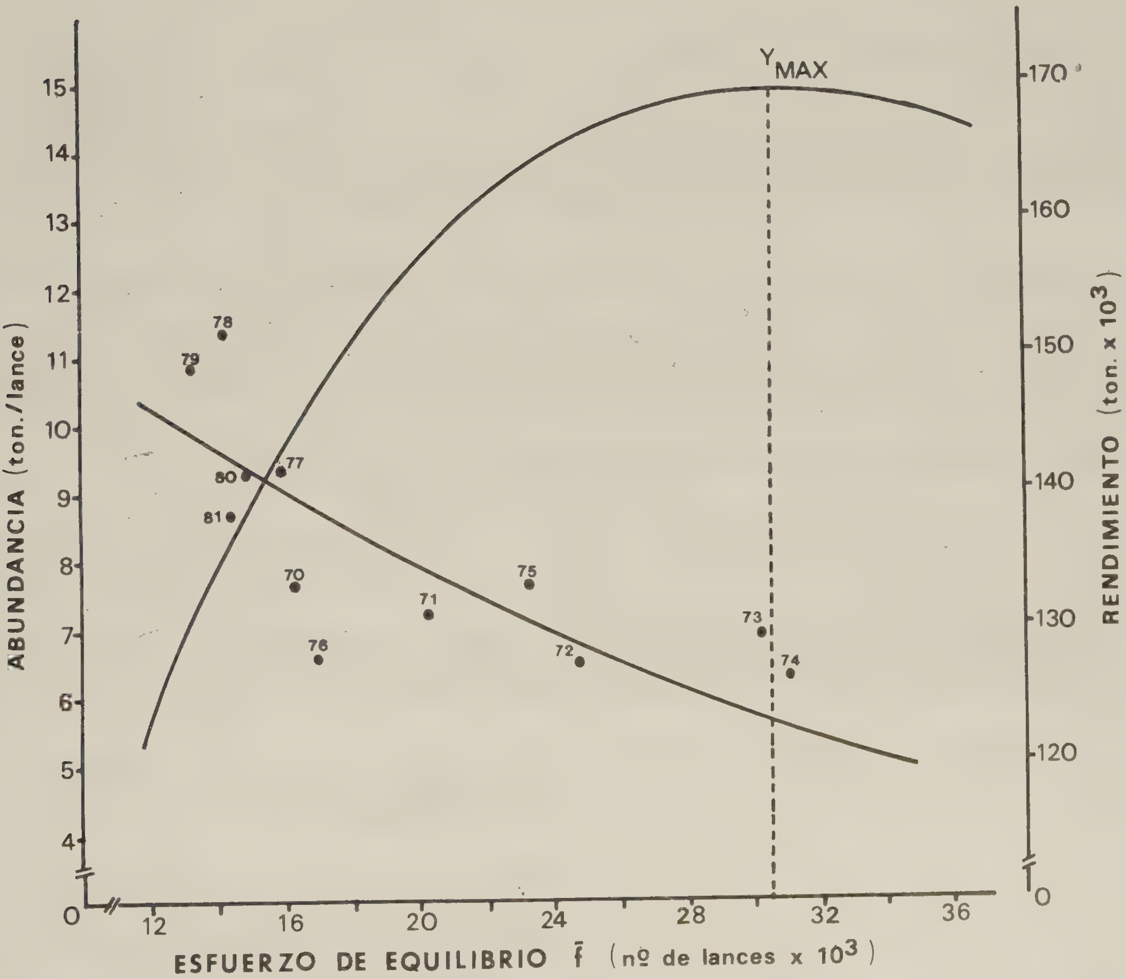

Fig. 6 - Relaciones entre abundancia/esfuerzo de equilibrio, y rendimiento/ esfuerzo de equilibrio, para los datos 1969-1981, ajustadas según modelo de Fox (1970)

El uso de este modelo fue ampliamente discutido tomando en cuenta las siguientes consideraciones: a) los datos de las estadísticas de pesca utilizados presentan generalmente gran margen de error; b) la unidad de esfuerzo usada puede no representar la verdadera intensidad de la pesca tanto por diferencias en el poder de pesca de la flota, que es heterogenea, como por las razones discutidas anteriormente; c) este modelo presenta sabidos inconvenientes cuando aplicado a peces pelágicos en los cuales ocurren concentraciones de los cardúmenes en determinadas áreas a medida que la población se reduce, siendo que la CPUE puede no acusar alteraciones, una vez que éstas son compensadas por cambios en el coeficiente de capturabilidad; y d) el modelo no puede prevenir eventos descontinuos, como fallas en el reclutamiento o en el desove, tan comunes en las poblaciones de peces pelágicos, que frecuentemente resultan en colapsos de stocks.

Otros modelos

Mortalidad natural: la tasa de mortalidad natural fue calculada a través de la ecuación de Pauly (1980) para clupeidos, según la cual:

$$\log_{10} \frac{M}{0.6} = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

usando parámetros con los siguientes valores:

$L_\infty$ = 24.0 cm

K = 0.62

T = 22°C

El valor encontrado fue M=0.74

Los parámetros de crecimiento empleados en esta ocasión fueron calculados a partir de datos parciales de frecuencia de clases de talla y por tanto el valor de M representa apenas una primera aproximación de la mortalidad natural de la especie, la que tendrá que ser revisada cuando se obtengan parámetros más satisfactorios.

Con estos valores se aplicaron los modelos de rendimiento por recluta (Beverton y Holt, 1957; Ricker, 1975) y análisis de cohorte (Pope, 1972) con la intención de obtener una evaluación preliminar del stock por estos métodos, estimándose una mortalidad por pesca de F= 0.8 y una captura total permisible de 201 000 ton. Estos todavía se consideran como resultados preliminares dado el limitado volumen de información disponible, y los estudios respectivos deben ser continuados por el GPE.

Utilización de sardina viva como carnada en la pesca de atún

Con la implantación de la pesca de atún, las autoridades y empresarios de la pesca de sardina manifestaron cierta preocupación en relación al impacto que podría causar la captura de ejemplares muy jóvenes de sardina para ser usados como "carnada-viva".

Conociendo el número de embarcaciones que operan en este tipo de pesca (alrededor de 60 embarcaciones) y la cantidad promedio de sardina viva usada para estos fines por cada barco se estimó en 1 000 ton. el total de sardina capturada anualmente.

Considerando que la talla promedio de las sardinas usadas como carnada es de 10 cm y empleando un valor de 0.74 para la mortalidad natural se calculó cual sería el rendimiento en peso de éstas en caso de que no fuesen pescadas.

Se obtuvo un valor de 2 400 ton. de sardinas con una talla de 17 cm, las cuales dejarían de ser reclutadas al stock adulto. Conviene recordar que no toda esta cantidad disponible a la pesca sería efectivamente capturada, debido a los efectos posteriores de la mortalidad. De esto se deduce que esta pesquería no implica alteraciones importantes para el stock adulto, a pesar de esto se ha recomendado el cuidadoso seguimiento y reglamentación de la misma.

### Estimación de la biomasa total

Levantamientos acústicos cuantitativos.- en el período de 1974/80 se realizaron 8 campañas a lo largo de toda el área de ocurrencia para estimar la biomasa de sardina a través de métodos hidroacústicos cuantitativos (Rijavec y Amaral, 1977), habiéndose encontrado valores que variaron entre 142 000 y 414 000 ton, con media de 250 000 ton. En esta ocasión se consideró que ésta era una sub-estimación, visto que las capturas anuales de 1977-80 presentaban valores de alrededor de 140 000 ton.

Infelizmente la discontinuidad de estas campañas ha impedido el seguimiento sistemático de las fluctuaciones, lo que habría permitido interpretar mejor la situación actual y dimensionar el stock.

Huevos y larvas.- Matsuura (1977), utilizando resultados de campañas de reconocimiento de huevos y larvas realizadas en 1969/70, 1970/71 y 1971/72 estimó la magnitud del stock desovante entre $0.5 \times 10^6$ y $1.0 \times 10^6$ ton, y para el período 1974/75 y 1975/76, en $1.7 \times 10^6$ y $3.3 \times 10^6$ ton. respectivamente. Al contrario de la evaluación por métodos hidroacústicos estos valores representarían una sobre estimación.

### Comportamiento de los cardúmenes en relación con las condiciones oceanográficas

Las oscilaciones de la estructura oceanográfica parecen determinar la disponibilidad de sardina a la pesca, provocando dislocamiento y concentración de los cardúmenes en diferentes regiones del área de distribución (PDP/SUDEPE, 1981 b).

En 1979 se observó una masa de agua fría en la costa de Río de Janeiro que provocó la desaparición de los cardúmenes en esta área, los cuales se dislocaron en su mayoría para el litoral de San Pablo.

En 1980, fenómenos similares provocaron grandes concentraciones a poca profundidad en el litoral de Santa Catarina facilitando las operaciones de la flota con un aumento en la capturabilidad del recurso.

En 1981 nuevamente se observaron altas concentraciones en el litoral paulista.

Todo indica que la estructura oceanográfica característica de invierno, cuando no hay formación de termoclina en pequeñas profundidades, provoca la dispersión de los cardúmenes de sardina, ya que, aparentemente, la temperatura actuaría en estos casos como factor limitante. Por otro lado en el verano se observa una mayor concentración de los individuos a menores profundidades, favoreciendo así su captura, la cual está basada en la identificación visual de los cardúmenes.

### Medidas de administración

En 1976, preocupada con la caída de la producción de sardina en ese año y sabedora del comportamiento de otros stocks de peces pelágicos intensamente explotados en otras regiones del munco, la SUDEPE decidió adoptar algunas medidas que permitiesen proteger el stock de la pesca excesiva. Citamos a seguir aquellas que a la fecha se encuentran en vigor:

- tamaño mínimo de captura, establecido en 17 cm, el cual corresponde a la talla media de inicio de la primera madurez sexual;

- período de veda, fijado año a año por 30 a 40 días, de acuerdo con la previsión de la época en que habrá mayor intensidad del desove;

- captura máxima de sardina en toda el área de pesca estipulada en 200 000 ton.

- control del esfuerzo a través de la reglamentación de la concesión de nuevas licencias para los barcos pesqueros que desean capturar sardina.

## CONCLUSIONES Y PERSPECTIVAS

En vistas de las consideraciones citadas podemos concluir que:

- La estructura de la especie en el área no fue aún claramente definida, debiendo ser continuados los estudios para verificar las hipótesis propuestas sobre la existencia de más de una población.

- De la misma manera, deberán continuar los estudios sobre crecimiento para esclarecer los parámetros (principalmente K y $L_\infty$) así como una correcta interpretación de la lectura de la edad de los ejemplares para poder utilizar los datos en la aplicación de los modelos de evaluación.

- Los estudios sobre la reproducción ya permiten establecer las características del desove de *S. brasiliensis*, delimitando el tipo, época y área del desove.

- La pesca presenta algunas señales de colapso, la disponibilidad de los cardúmenes es escasa y han disminuido bruscamente las capturas en los últimos años.

- Esta disminución puede ser debida a las oscilaciones en la estructura oceanográfica que provocan el desplazamiento de cardúmenes hacia áreas de difícil acceso para la flota comercial; la disminución del tamaño de la población desovante debido a sobrepesca; o fallas del reclutamiento.

- El análasis de los datos disponibles y la aplicación de modelos matemáticos para diagnosticar la real situación del stock no ha permitido establecer las verdaderas causas de este comportamiento, y parece evidente que la aplicación de modelos de producción general no es adecuada. Es necesaria la sistematización de estudios de evaluación de biomasa por métodos independientes, como levantamientos acustico-cuantitativos y de huevos y larvas, o tal vez marcación.

- Se torna imprescindible ampliar las investigaciones que permitan conocer la real situación del recurso, ya que este representa un alimento de bajo costo y consumo popular a cuya captura están vinculados amplios sectores de la población de pescadores de la región Sudeste del Brasil.

## RECONOCIMIENTOS

En esta contribución se han compilado resultados de trabajos llevados a cabo por los siguientes científicos del PDP/SUDEPE: J.C. Amaral (Brasilia), M. M. Bittencourt (Sao Paulo), R. de D. Cardoso (Santa Catarina), L. G. Domit (Paraná), V. J. Isaac Nahum (Sao Paulo), S. Jablonski (Río de Janeiro) y S. A. Saccardo (Sao Paolo) así como C.L.D.B. Rossi-Wongtschowski del Instituto Oceanográfico de la Universidad de Sao Paulo y H. Valentini del Instituto de Pesca-Secretaria de Agricultura-Sao Paulo.

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*NORTH WEST ATLANTIC - ATLANTICO NORDOCCIDENTAL*

# THE DYNAMICS OF PELAGIC FISHERY RESOURCES OFF THE NORTHEASTERN COAST OF THE UNITED STATES UNDER CONDITIONS OF EXTREME FISHING PERTURBATIONS

by

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## Resumen

Los recursos pesqueros en las áreas mar afuera frente a las costas Noreste de los Estados Unidos, han experimentado perturbaciones significativas debida a la pesca durante los últimos 25 años. Antes de 1960 esta área era casi exlusivamente explotada por los Estados Unidos con solo algunos barcos canadienses dedicados a la explotación de peces. Esta actividad extractiva se concentró básicamente en especies de alto valor en el mercado Norteamericano, estas eran principalmente especies de fondo y conchas marinas. La única pesquería pelágica significativa era la pesquería de arenque juvenil a lo largo de la costa de Maine y la bahía de Fundy. Algunas especies semipelágicas como la merluza dorada soportaron una pesquería solo modesta. La pesquería en el área del Banco de Georges era casi exclusivamente basada en peces de fondo, platija y la extracción de conchas. Prácticamente no hubo ninguna pesquería en el borde de la plataforma continental en el área al medio del Atlántico.

Pesquerías de flotas pesqueras de altura de Europa y Japón expandieron silenciosamente sus pesquerías a fines de 1960 y entraron en esta área. Un componente principal de estas pesquerías fue dirigido a los stocks pelágicos de arenque del Atlántico y caballa del Atlántico capturados en el Banco de Georges y en la porción exterior de la plataforma continental del área del Atlántico Central. Estas pesquerías también se concentraron en la merluza dorada semipelágica y posteriormente capturó grandes cantidades de calamar (especies de *Illex* y *Loligo*), cazones y tiburones. Esta pesquería alcanzó su máximo a principio de los años 1970s y las médidas de regulación comenzarón a tener como tal resultado una disminución del esfuerzo de pesca. En 1977 con la extensión de la Jurisdicción del estado costero por parte de Estados Unidos las pesquerías por parte de flotas extranjeras de altura fueron casi virtualmente eliminadas.

Los resultados de los reconocimientos con redes de arrastre del Northeast Fisheries Center (Clark and Brown 1977) indican que la biomasa de peces y calamares en toda el área disminuyeron en un 65% en el período de 1964 a 1975 con una estabilización en el período. El Northeast Fisheries Center tuvo la oportunidad para seguir la respuesta de los stocks a las medidas drásticas de disminución del esfuerzo de pesca que resultó de las regulaciones restrictivas.

La reducción de la presión de pesca ha sido selectiva en el sentido de que todavía continua una presión de pesca muy fuerte sobre los peces de fondo y los stocks de platija aun cuando estas se han reducido significativamente por debajo de lo que era en sus períodos máximos. Sin embargo, para el caso de merluza dorada, arenque y caballa, la presión de pesca es ahora casi inexistente. A pesar de esta reducción en la presión de pesca hay una virtual ausencia de arenque en el Banco de Georges en el momento. La última clase anual fuerte fue la de 1970 y de cuando esta clase anual fue removida de la población (presumiblemente por una fuerte pesquería) ha habido muy poca evidencia de la presencia de arenque en el Banco de Georges.

La caballa ha ido aumentado lentamente y ahora se encuentra a niveles similares a aquellos que tenía a inicios de los años 1960s. Su abundancia es mucho menor que la que tenía durante los inicios de los años 1970s cuando dos clases anuales muy buenas ingresaron a la pesquería. Estas clases anuales entraron a la pesquería en el período en que las fuertes clases anuales de arenque que habían soportado el desarrollo de la pesquería de altura de arenque estaban siendo removidas del escenario.

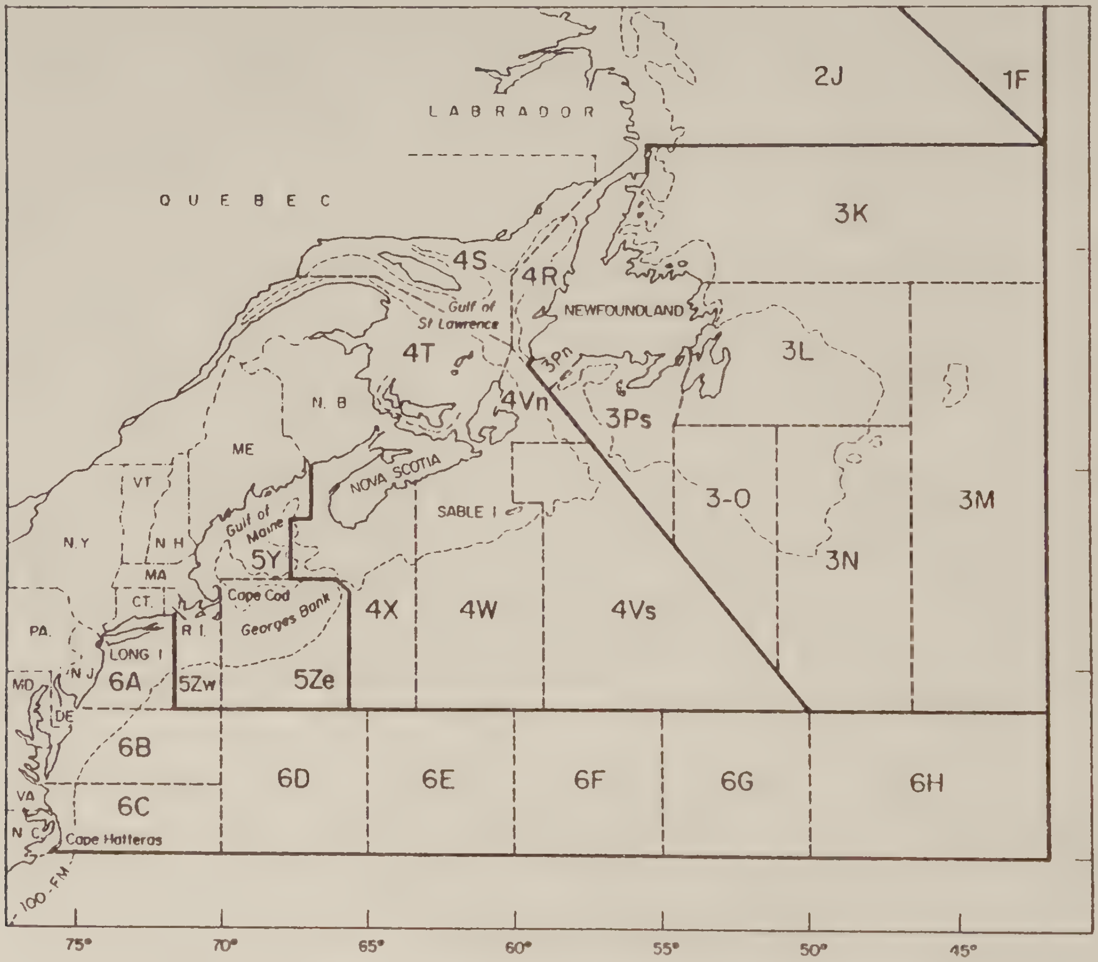
La merluza dorada se ha recuperado solo ligeramente y ya no es la especie dominante en el área. Los stocks de tiburones todavía se mantienen a niveles relativamente altos a pesar de la intensa pesquería a que fueron sometidos hacia el final de la época en que actuó la pesquería de altura de otros estados, y en estos momentos representan el mayor volumen de predatores de peces en esta área.

Los calamares, tanto *Loligo* como *Illex*, se expandieron en la última parte del período correspondiente a las actividades de la pesquería de altura alcanzando sus períodos máximos después que las poblaciones de caballa y arenque. Estas poblaciones se encuentran ahora ligeramente más bajas de lo que estuvieron antes, pero todavía son abundantes. A mediados de los años 1970s hubo una expansión de la población de *Ammodytes* la cual parece haber desaparecido nuevamente.

Hacia 1980 los recursos de peces de fondo comenzaron a recuperar esencialmente la misma mezcla de especies que existió antes de que comenzara la intensa pesquería por las flotas de altura. Sin embargo, muy recientemente, las poblaciones de pescadilla han sido reducidas drásticamente por una pesquería muy intensa por parte de los Estados Unidos y Canadá y aun cuando todavía constituyen un principal componente las capturas (no como el arenque que es casi inexistente) ocupa una proporción menor de la biomasa del ecosistema que la que ocupó en el período anterior.

## INTRODUCTION

Finfish and squid resources in the offshore areas off the Northeast Coast of the United States (Fig. 1, International Commission for the Northwest Atlantic Fisheries (ICNAF)/Northeast Atlantic Fishery Organization (NAFO) Subareas 5 and 6) have experienced significant perturbations due to fishing during the past 25 years. Prior to 1960, this area was fished (except for scallops) almost exclusively by the United States. These finfish vessels concentrated primarily on groundfish and Atlantic herring[1] (*Clupea harengus*), species of high market value to Canada and the United States (US). Although herring constituted a major fishery, it was predominantly directed towards juveniles which were harvested in inshore areas and packaged as sardines. Distant water fleets from Europe and Japan expanded their fisheries in the 1960's in this area and increased catch of both traditional and newly fished species occurred (Fig. 2). The sum total of these fisheries affected the entire offshore finfish plus squid resources, including the groundfish, e.g. Atlantic cod (*Gadhus morhua*), haddock (*Melanogrammus aeglefinus*), flounder, etc., pelagics, e.g. Atlantic mackerel and herring, semi-pelagics, e.g. silver hake (*Merluccius bilinearis*), and *Illex* and *Loligo* squid. However, by far the greatest effort was directed at herring and mackerel.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6F
6G
6H
VA
6C
N C
Cape Hatteras
100 FM
50°
45°
40°
35°
75°
70°
65°
60°
55°
50°
45°

Fig. 1. Northwest Atlantic Ocean partitioned into ICNAF/NAFO Subareas and Divisions.

Beginning in the early 1970's, ICNAF began catch regulations to restrict fishing mortality in these waters. In 1972 the ICNAF treaty was changed to allow for the national allocation of catch quotas (prior to that only a single overall quota could be established).

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[1] Common names of fish are those given in Robins 1980; the term Atlantic before cod, mackerel, and herring is dropped after the first usage.

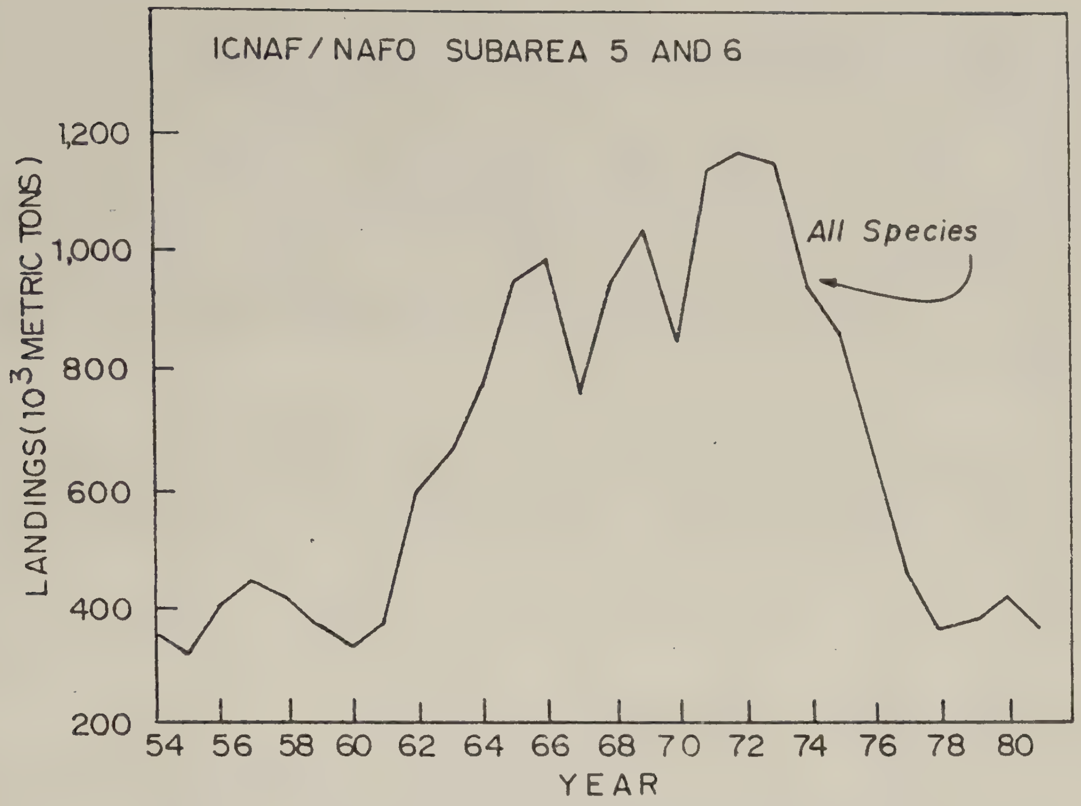

Fig. 2. Total nominal catch of all species in ICNAF/NAFO Subareas 5 and 6, 1954-81.

Immediately in January 1972 a total allowable catch with national allocations was established for herring. Mackerel catch regulations were first implemented in 1973, much earlier in relationship to the start (1968) of that heavy distant water fleet fishery than for herring. By 1974, a full array of restrictions that did reduce total fishing effort were in place. In 1977 the enactment of 200-mile fishery zones by Canada and the United States resulted in further reductions, especially drastic in the distant water fleet's fishing effort in the waters south of Nova Scotia. However, after extended jurisdiction, there were increases in fishing effort in various US and Canadian fisheries primarily for groundfish.

In examining trends in fishery resources over time it is important to consider three interrelated factors that drive fishery systems: the physical environment, fishing, and biological interactions. The predominant factor in many fisheries systems is the driving force of the relative strengths of recruiting year-classes (Hennemuth et al., 1980). It is generally considered that it is in the survival of early life history stages (i.e. eggs and larvae) that the physical factors are most critical. Obviously the number of initial spawning products is determined by spawning stock size. The relative abundances of predators and food are also important. The effects of the physical environment, except for long-term climatic trends and the alteration of habitat, tend to average out over time as resources have evolved to exist in the environment in which they are found. This is also true of the interactions with the predator-prey biological components in the ecosystem. Thus, to a considerable extent the variations in recruitment can be dealt with as a statistical distribution problem (Hennemuth et al., 1980).

The entrance of humans as an extremely heavy predator introduces a factor outside of those with which species have evolved to coexist. To some extent fishing can be considered another form of predation to which these resources have adapted, and this is certainly logical when fishing effort is moderate and the market system causes the fishing effort to respond to the densities of the prey. However, this area of the Northwest Atlantic was subjected to extremely heavy fishing pressure that not only did not fluctuate with abundance of prey, but to some extent increased as fish stocks decreased.

The effects of fishing can be two-fold. First, there is the direct reduction of an individual resource, reducing its presence in the ecosystem for a considerable period of time. The length of time the resource is depressed in abundance depends to a certain degree on the presence and shape of any stock recruitment relationship and the chance interactions with environmental conditions that would produce strong year classes despite small spawning stocks. This kind of effect would, however, be expected to be entirely reversible over a fairly short time period. Secondly, beyond the direct effect on individual stocks there is the potential disruption of normal competitive predator-prey interrelationships which could alter the structure of the ecosystem and result in a change in species composition and dominance. Fishing can cause these interrelationships to be in a state of rapid disequilibrium as opposed to a less rapid or really different one. Changes in these interrelationships might be expected to be of a longer term, possibly semi-permanent nature.

This paper will review the historical patterns in nominal catch (i.e., those catches reported to the appropriate governmental statistics agencies and in this case recorded in NAFO files in Dartmouth, N.S., Canada), and abundance of the fisheries resources, and will discuss some hypotheses as to the responses of these stocks in the face of the extreme perturbations resulting from heavy fishing pressure.

## TRENDS IN FISHERIES AND POPULATIONS

### Total Finfish Plus Squid Resource Abundance

Estimates of resource abundance are available from both commercial and recreational fisheries data and from research vessel surveys (Grosslein, 1969; Clark, 1981). Taken together they provide a comprehensive picture of resource trends. Estimates from fisheries data are limited to those species supporting the largest and most important fisheries such as mackerel, herring, haddock, silver hake, cod, and yellowtail flounder (*Limanda ferruginea*). Standardized research vessel bottom trawl surveys provide comprehensive coverage over the Georges Bank, Gulf of Maine, and Mid-Atlantic areas. They have been conducted since 1963 in the autumn and 1968 in the spring by research vessels of the Northeast Fisheries Center (NEFC). Prior to 1967 surveys went only as far south as Hudson Canyon; since then they have been extended south to Cape Hatteras. These annual autumn and spring research vessel surveys have been supplemented occasionally by summer and winter surveys. Regular inshore surveys have also been conducted by the State of Massachusetts for part of this coastal area. In addition, research vessels from the Soviet Union, Poland, the Federal Republic of Germany, the German Democratic Republic and France have cooperatively surveyed the area at various times (Azarovitz, 1981).

Survey results indicate that the offshore finfish and squid biomass in NAFO Subareas 5 and 6 decreased by 65% in the period 1964-1975 following the period of greatest catches (Clark and Brown, 1977; Fig. 3; Table 1). The downward trend then reversed itself as resources began to recover after catches were reduced (Clark and Brown, 1979) and by 1980-81 biomass had increased about 50% of the way towards that existing in the early 1960's (Resource Assessment Division, 1982).

### Herring

Herring have been harvested from inshore waters of the New England coast for at least 400 years. The major fishery for herring in the Northwest Atlantic during the early part of the nineteenth century was for large herring in the eastern Maine-Bay of Fundy area. The canning of sardines began in 1875 and was a leading fishery for herring through the first half of the twentieth century. The catch of herring in the Northwest Atlantic from Newfoundland to North Carolina remained fairly constant from 1920 to 1940 between 60,000 and 100,000 tons (Anthony, 1972). The total catch more than doubled in the late 1940's and then gradually declined to approximately 180,000 tons through the 1950's.

Table 1: Stratified mean catch per tow (kilograms) for selected species of finfish and squid, NEFC autumn bottom trawl survey data, 1967-1980, Middle Atlantic, Southern New England, Georges Bank, and Gulf of Maine (Strata 61-76, 1-30, and 36-40).

| Species | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cod | 4.5 | 5.0 | 4.4 | 5.1 | 4.6 | 6.4 | 6.4 | 2.9 | 4.4 | 4.2 | 5.7 | 9.0 | 7.0 | 5.4 |
| Haddock | 8.1 | 5.8 | 3.8 | 4.0 | 2.4 | 2.2 | 3.3 | 1.3 | 4.4 | 8.7 | 9.0 | 18.9 | 11.5 | 7.7 |
| Redfish | 8.2 | 13.6 | 7.9 | 11.1 | 7.9 | 8.3 | 5.7 | 7.7 | 13.4 | 5.1 | 5.8 | 7.1 | 5.4 | 4.2 |
| Silver hake | 2.3 | 2.5 | 1.8 | 2.0 | 2.4 | 3.6 | 2.6 | 1.9 | 4.2 | 5.6 | 3.6 | 4.0 | 3.4 | 3.8 |
| Red hake | 1.0 | 1.6 | 1.8 | 1.3 | 1.7 | 2.6 | 1.6 | 0.7 | 3.0 | 2.1 | 2.9 | 2.4 | 2.1 | 3.4 |
| Pollock | 1.2 | 1.9 | 4.2 | 1.2 | 2.2 | 2.7 | 2.1 | 1.8 | 1.2 | 10.5 | 5.2 | 3.4 | 2.6 | 1.6 |
| Yellowtail | 4.8 | 5.6 | 5.2 | 4.2 | 2.9 | 7.9 | 1.6 | 1.0 | 0.5 | 0.7 | 1.1 | 1.0 | 0.8 | 1.7 |
| Other flounder | 4.6 | 5.4 | 5.1 | 5.1 | 3.5 | 4.3 | 4.2 | 3.5 | 4.1 | 4.9 | 7.6 | 7.6 | 6.7 | 8.2 |
| Herring | 0.3 | 0.1 | 0.1 | 0.0[1] | 0.3 | 0.1 | 0.0[1] | 0.0[1] | 0.1 | 0.0[1] | 0.0[1] | 0.1 | 0.0[1] | 0.0[1] |
| Mackerel | 0.3 | 0.2 | 1.1 | 0.0[1] | 0.0[1] | 0.1 | 0.0[1] | 0.0[1] | 0.0[1] | 0.0[1] | 0.0[1] | 0.1 | 0.1 | 0.1 |
| Other finfish[2] | 80.9 | 47.1 | 89.2 | 49.3 | 33.6 | 43.3 | 54.5 | 27.4 | 49.9 | 50.2 | 62.7 | 53.0 | 71.0 | 63.5 |
| Short-finned squid | 0.2 | 0.3 | 0.1 | 0.3 | 0.4 | 0.3 | 0.3 | 0.4 | 1.5 | 7.8 | 3.9 | 4.8 | 7.5 | 3.4 |
| Long-finned squid | 2.8 | 5.1 | 6.8 | 2.2 | 2.1 | 4.6 | 7.6 | 5.8 | 7.6 | 8.1 | 5.7 | 3.0 | 2.7 | 5.6 |
| Total finfish and squid | 119.2 | 94.2 | 131.5 | 85.8 | 64.0 | 86.4 | 89.9 | 54.4 | 94.3 | 108.0 | 113.3 | 104.4 | 120.7 | 108.6 |

[1] Less than 0.05.

[2] Does not include data for tunas, sharks, swordfish, American eel, or white perch.

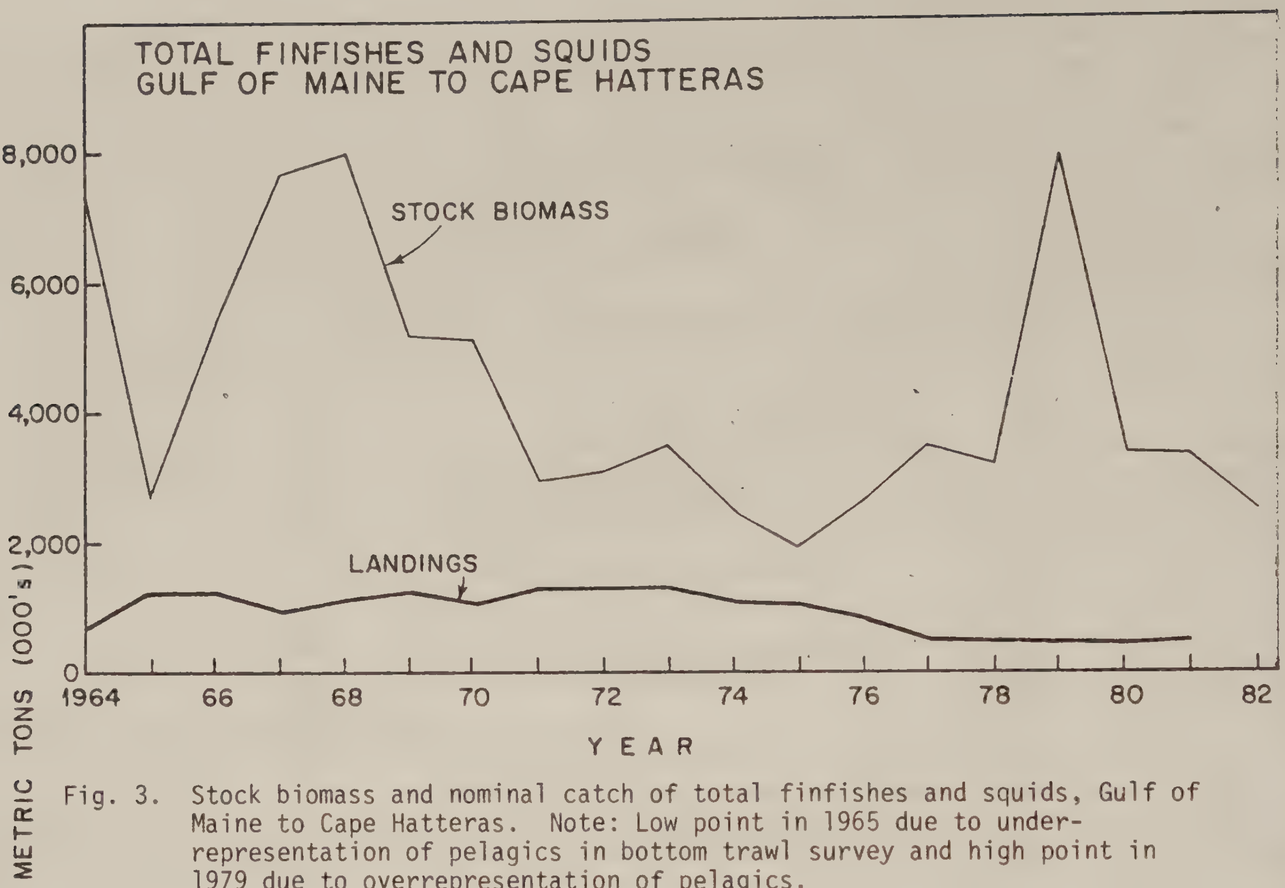

Fig. 3. Stock biomass and nominal catch of total finfishes and squids, Gulf of Maine to Cape Hatteras. Note: Low point in 1965 due to underrepresentation of pelagics in bottom trawl survey and high point in 1979 due to overrepresentation of pelagics.

During the 1960's the catch increased dramatically to over 900,000 tons as new fisheries developed. The very important Georges Bank fishery began in 1961 and the Nova Scotia adult purse seine fishery began in 1964-65. The Gulf of St. Lawrence fishery intensified after 1965, and the western Gulf of Maine-Jeffreys Ledge fishery for adult herring began in 1967. In the Georges Bank-Gulf of Maine area, there have been two juvenile fisheries and in recent times three adult fisheries. The two juvenile fisheries occur along the Maine coast and along the New Brunswick coast. The adult fisheries (also taking some age 3 juvenile herring) have existed on Georges Bank, Jeffreys Ledge in the western part of the Gulf of Maine, and off southwestern Nova Scotia (Anthony and Waring, 1980a). All three adult herring fisheries began as autumn fisheries, harvesting spawning herring of age 4 and older, while the juvenile fisheries have concentrated on harvesting young herring ages 1-3. In the early 1900's the juvenile herring fishery on the Maine coast harvested about 60,000 tons per year and then declined to 25,000 tons on average from 1917 to 1940. The catch increased from the late 1940's through the 1950's to about the 60,000 ton level and then again declined to less than half of that from 1970 to 1975. After 1975 the Maine juvenile fishery began to improve again with catches varying from 30,000 to 48,000 tons. The New Brunswick juvenile fishery fluctuated in a similar pattern to that along the Maine coast although at a higher level of catch. The catch of herring from the New Brunswick juvenile fishery averaged 56,000 tons from 1964 to 1969, 28,000 tons from 1970 to 1976, and 34,000 tons since then.

The Gulf of Maine fishery for adult herring began in 1967 with annual catches increasing to nearly 40,000 tons up to 1972 as the accumulated stock was fished up. In 1967-68 when the fishery began, the stock size (age 4 and older) averaged 150,000 tons. After 1972 until the present time, catches have fluctuated between 15,000 and 24,000 tons annually and the stock size has fluctuated between 31,000 and 88,000 tons. The adult fishery off southwestern Nova Scotia was a minor fishery until the mid-1960's when new processing plants were built and catches rapidly increased to a peak of 178,000 tons in 1970. This stock is several times larger than the stock or stocks being fished upon in the western Gulf of Maine area. In 1967-68 the stock size (age 4 and older) averaged

547,000 metric tons. This stock has since been overfished and the catches have been declining steadily since its large increases in the late 1960's to levels of 70,000 tons in the early 1980's. The stock size decreased to a low of 95,000 tons in 1979 and slightly increased in 1980-82 (Figure 4).

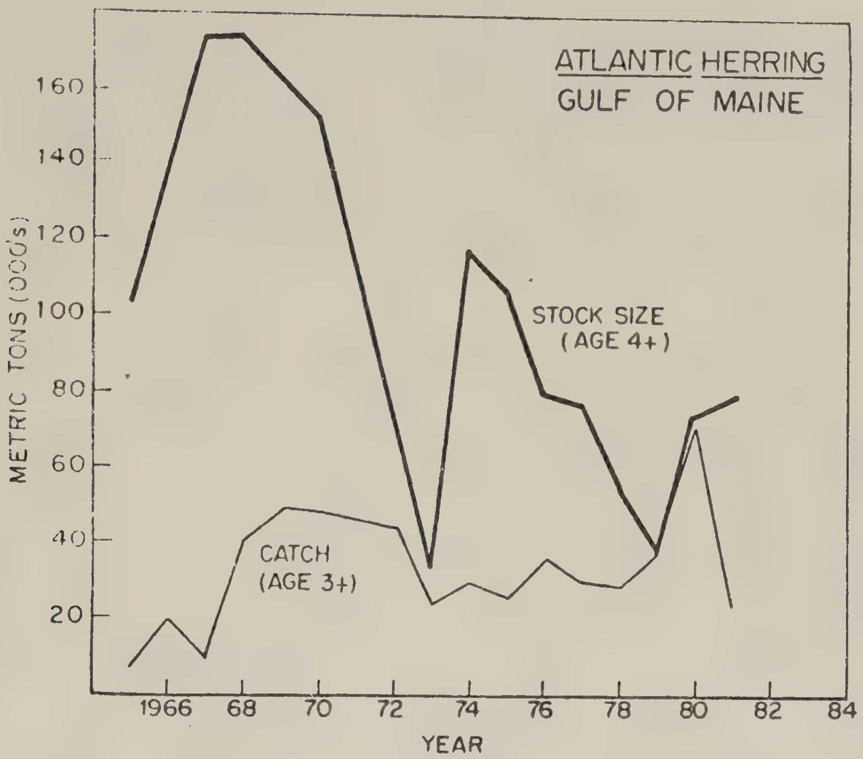

Fig. 4. Stock size and nominal catch of Atlantic herring in the western Gulf of Maine.

The largest herring stock and fishery in the Northwest Atlantic has been the Georges Bank stock which was not fished until 1961 (Anthony and Waring, 1980b). After discovery of this stock by the Soviet Union exploitation increased rapidly until 13-14 nations were fishing on this stock in the late 1960's and catches increased to 374,000 tons in 1968. The stock size (age 4 and older) reached a peak in 1967 of 1.4 million tons, rapidly declined during the early 1970's to 144,000 tons in 1973, and recovered slightly in 1974 to 342,000 tons due to a very strong 1970 year class. This recovery only delayed overfishing by a few years and the fishery ended in 1977 (Fig. 5). The production of larvae from the Georges Bank spawning areas since 1977 has been nearly nonexistent.

In summary, by 1982 the Georges Bank fishery had ended, the Nova Scotia fishery was declining, the Jeffreys Ledge or western Gulf of Maine fishery was continuing at its recent level of harvest and the two juvenile fisheries were also continuing at moderate levels of harvest.

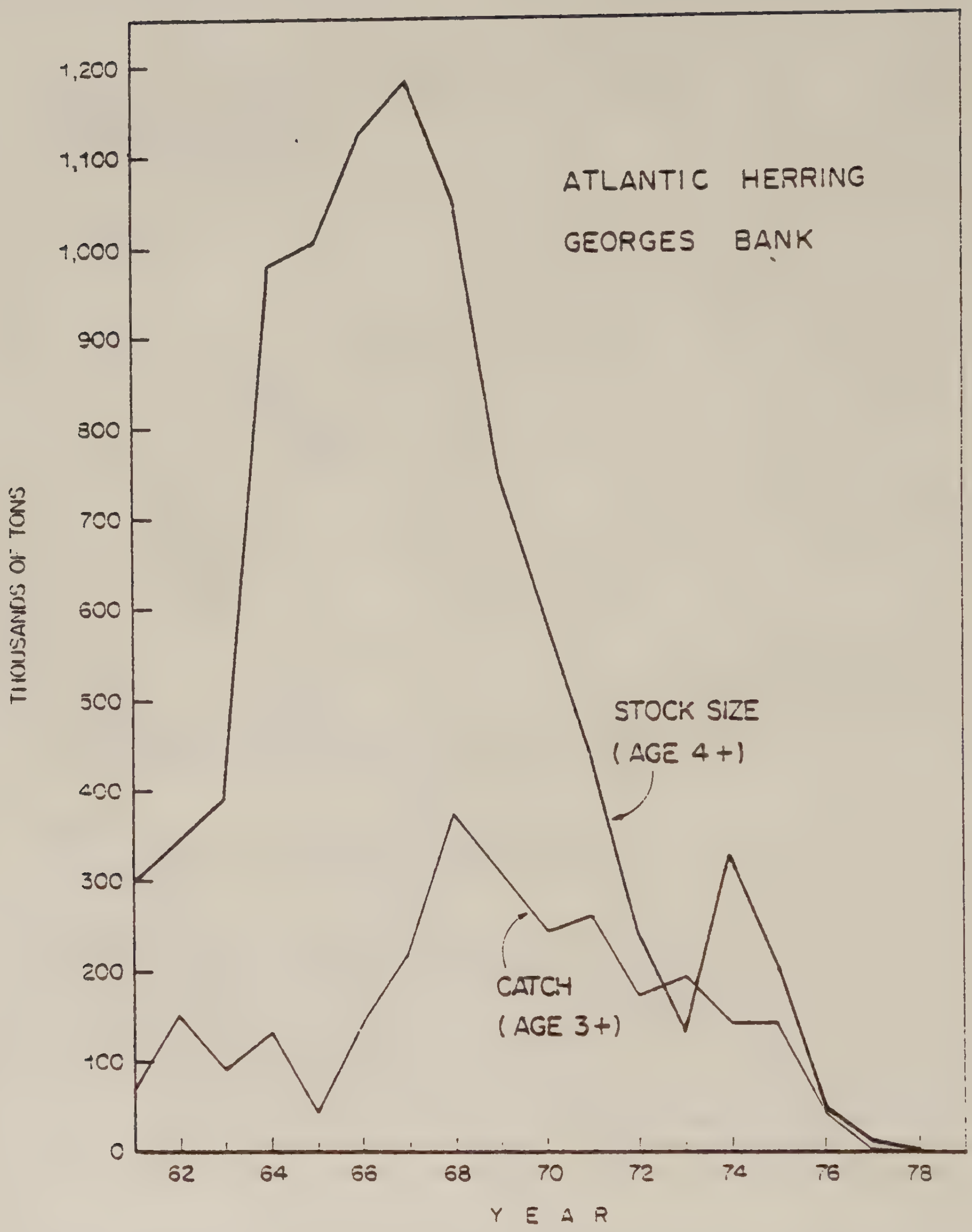

Fig. 5. Stock size and nominal catch of Atlantic herring on Georges Bank.

## TRENDS IN FISHERIES AND POPULATIONS

### Mackerel

Mackerel in the Northwest Atlantic are distributed between Labrador and North Carolina and undergo extensive spring and autumn migrations. Although spawning occurs in two major areas, the New York Bight and the Gulf of St. Lawrence, the entire population has been treated as a single stock. Commercial catches have fluctuated widely since they were first recorded in 1804. Until the early 1960's, the fishery was conducted entirely by the US and Canada. Catches varied markedly due to apparent population fluctuations as well as to changes in market conditions, fishing methods, and areas fished, and reached a high of about 106,000 tons in 1884. US and Canadian commercial catches achieved a level of relative stability during 1925-49 when they averaged 35,200 tons per year (Anderson and Paciorkowski, 1980). Catches then declined, reaching a low of 6,100 tons in 1959.

Beginning in 1961, distant-water fleets commenced fishing for mackerel. An intensive international fishery, conducted mainly off the US coast during November-May on over-wintering concentrations, began in 1968 as catches jumped to 80,800 tons from 34,100 tons in 1967. Total stock biomass (ages 1 and older) increased from around 300,000 tons during 1962-65 to a peak of 1.8 million tons in 1970-71 due to a succession of four good year classes produced during 1966-69, including an outstanding 1967 year class. Commercial catches increased to a peak of nearly 430,000 tons in 1973. Following the period of intense fishing which lasted until 1977 (77,600 tons), when jurisdiction over fisheries was extended to 200 miles by the US and Canada, stock biomass declined to an estimated 323,000 tons in 1978 (Anderson, 1982) (Fig. 6). Catch regulations imposed by ICNAF were designed to prevent the stock biomass from decreasing below that in the early 1960's prior to the beginning of heavy fishing and this was achieved. Recruitment in recent years has been markedly below that observed from 1966 to 1974, with relatively poor year classes in 1975-77. Aided by relatively low commercial catches during 1978-82 (average of about 27,000 tons per year) and a slight improvement in recruitment, the stock increased almost 75% in weight from 1978 to about 560,000 tons at the beginning of 1983. Given the unusual nature of having four good year classes in the late 1960's (previous peaks were recorded in 1835-40 and 1880-84; Sette and Needler, 1934), it would be prudent not to base fishery expectations on the late 1960's and early 1970 experience.

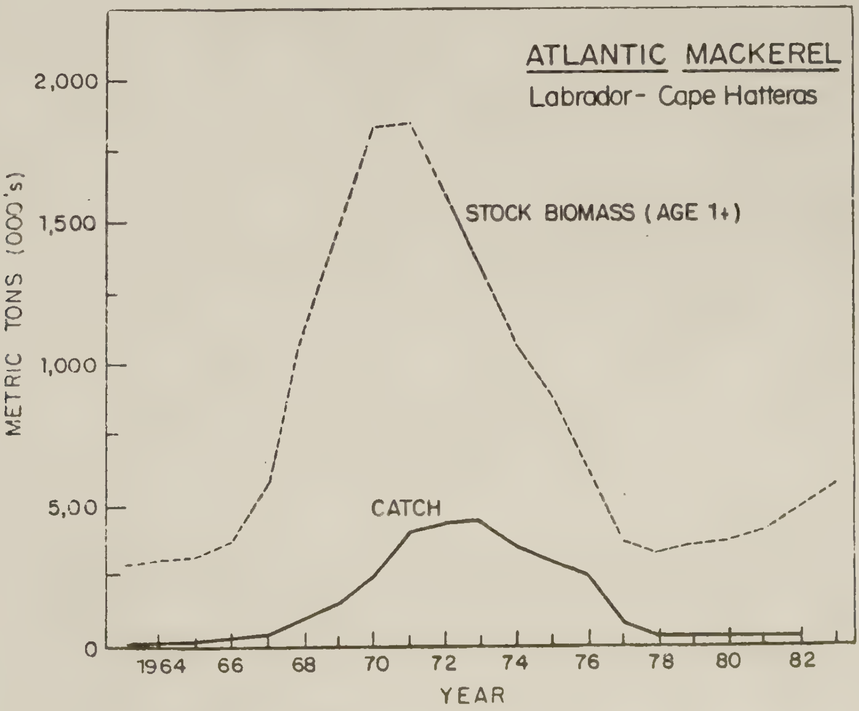

Fig. 6.

Stock size and nominal catch of Atlantic mackerel from Labrador to Cape Hatteras.

Although the bulk of the international catch over time has been commercial, a recreational fishery for mackerel has existed for many years along the east coast from Maine to North Carolina. Recreational catches are not known precisely, although estimates have been made periodically since 1960 from national and regional angler surveys. Estimated recreational catches peaked at about 16,000 tons in 1970 and in the last several years have been 3,000-4,000 tons. By comparison the US commercial catch since 1953 has averaged only about 2,200 tons annually, mainly due to a very limited domestic market, whereas the Canadian catch since 1965 has averaged about 16,500 tons annually.

## Silver Hake

Silver hake are widely distributed in the Northwest Atlantic between Newfoundland and South Carolina and inhabiting waters off the US coast have been considered to represent three separate stocks: the Gulf of Maine, Georges Bank, and Southern New England-Middle Atlantic (Anderson et al., 1980a). Catches from the Gulf of Maine taken by inshore US vessels averaged nearly 30,000 tons annually during 1955-64, but underwent a steady downward decline thereafter, with annual catches averaging 6,300 tons during 1971-82. The 1982 catch of about 2,100 tons was the lowest reported. Stock biomass (ages 1 and older) underwent a gradual decline from 220,000 tons in 1955 to only 20,000 tons in 1971 (Almeida and Anderson, 1981). Biomass has not recovered substantially from this low level, averaging only about 40,000 tons per year since 1970, but has exhibited a slight upward trend since 1977 (Fig. 7).

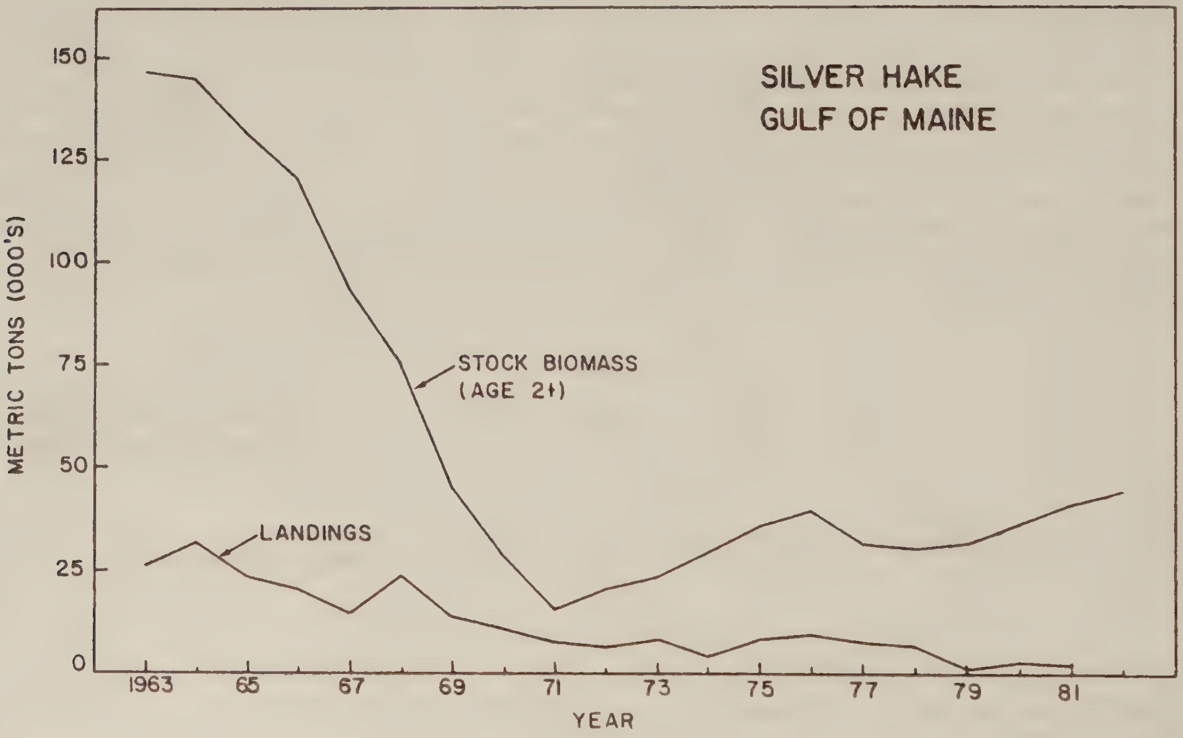

Fig. 7. Stock size and nominal catch of silver hake in the Gulf of Maine.

Catches from Georges Bank were fairly steady at an average of 19,000 tons per year during 1955-61 (totally US), but increased rapidly to a peak of nearly 240,000 tons in 1965 as the result of an intensive USSR fishery. Following a drop to only 18,400 tons in 1969, catches stabilized at an average of 68,000 tons during 1971-75, but again dropped due to decreasing stock size as well as restrictive regulations. Catches in 1979-81 were less than 2,000 tons annually. Stock biomass on Georges Bank increased from about 110,000 tons during 1955-57 to nearly 800,000 tons in 1963 and then dropped to about 170,000 tons in 1969-70 (Almeida and Anderson, 1981a). Following a brief increase to about 275,000 tons in 1973, stock biomass declined steadily to average about 25,000 tons during 1978-82 (Fig. 8).

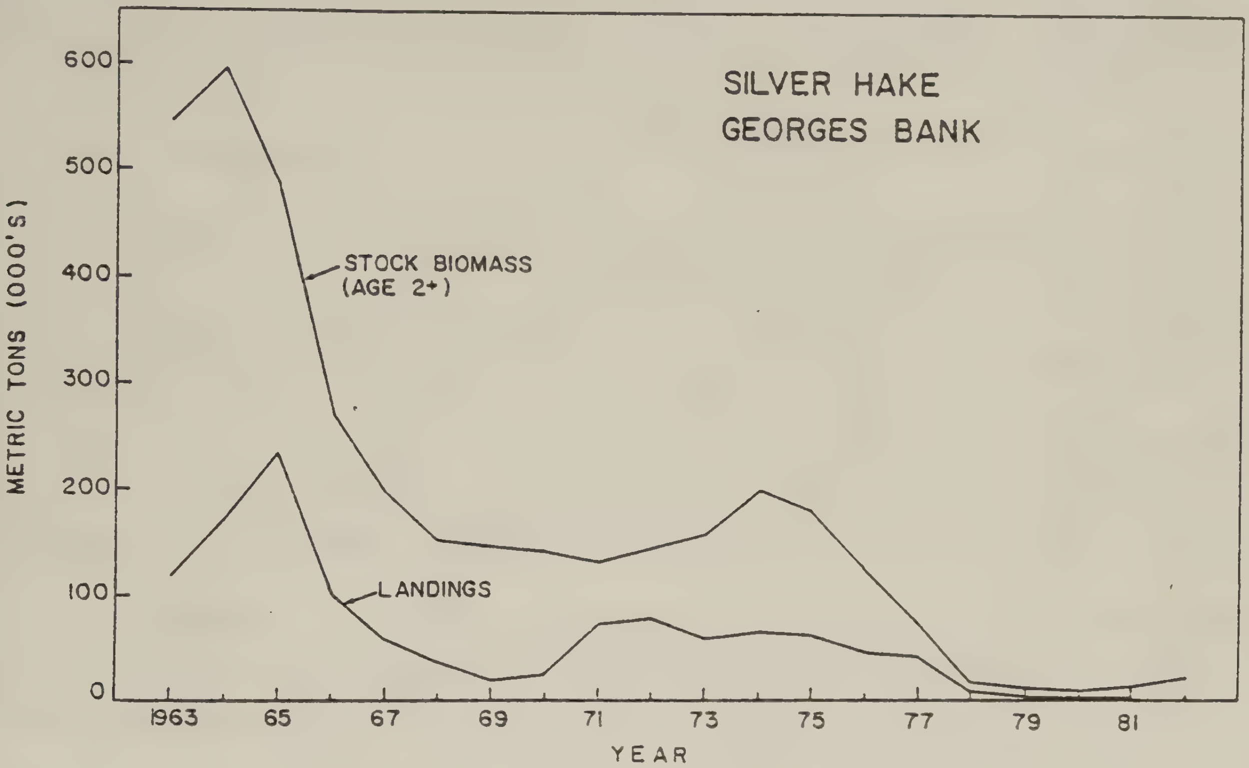

Fig. 8. Stock size and nominal catch of silver hake on Georges Bank.

Total catches (commercial and recreational) in Southern New England-Middle Atlantic averaged about 17,000 tons yearly during 1955-59 (all US), declined to about 10,000 tons in 1960, and increased steadily to around 137,000 tons in 1966. As on Georges Bank, the marked increase was due to an intensive USSR fishery which began in 1963. Estimated US recreational catches from marine angler surveys have averaged about 1,800 tons per year since 1960. Total international catches dropped to about 51,000 tons in 1967 and fluctuated between 19,000 and 67,000 tons until 1973, but then underwent a steady downward trend to 15,000-16,000 tons in 1980-81. Stock biomass (ages 1 and older) remained relatively steady at about 76,000 tons during 1955-59, improved to about 455,000 tons in 1965, and then dropped sharply to only 83,000 tons in 1970 (Almeida and Anderson, 1981a). After increasing briefly to 213,000 tons in 1973, stock biomass declined steadily to about 80,000 tons in 1982 (Fig. 9).

There were no strong year classes either during the period of relatively high stock biomass in the middle 1960's or during the period of low spawning stock existing since then. The Southern New England - Mid-Atlantic stock is producing modest size year classes at a spawning stock which is approximately 20 percent of the peak period. Georges Bank stock, however, has produced very small year classes from spawning stocks now less than 1/10th those of the early period. The Gulf of Maine stock which was reduced to similar low levels has also not rebuilt. Again the evidence is circumstantial with some indication there has been a decreased probability of good year classes when the spawning stock has reached extremely low levels as on Georges Bank and the Gulf of Maine. The latter stock, however, appears to have behaved somewhat differently than the offshore stocks as its reduction was not caused by high fishery removals to the same degree. The Gulf of Maine had a moderate level of fishing from the US inshore fleet for a long period of time. Landings were maintained at a fairly constant level through 1965 and then underwent a gradual decrease to a very minimal fishery at the present time.

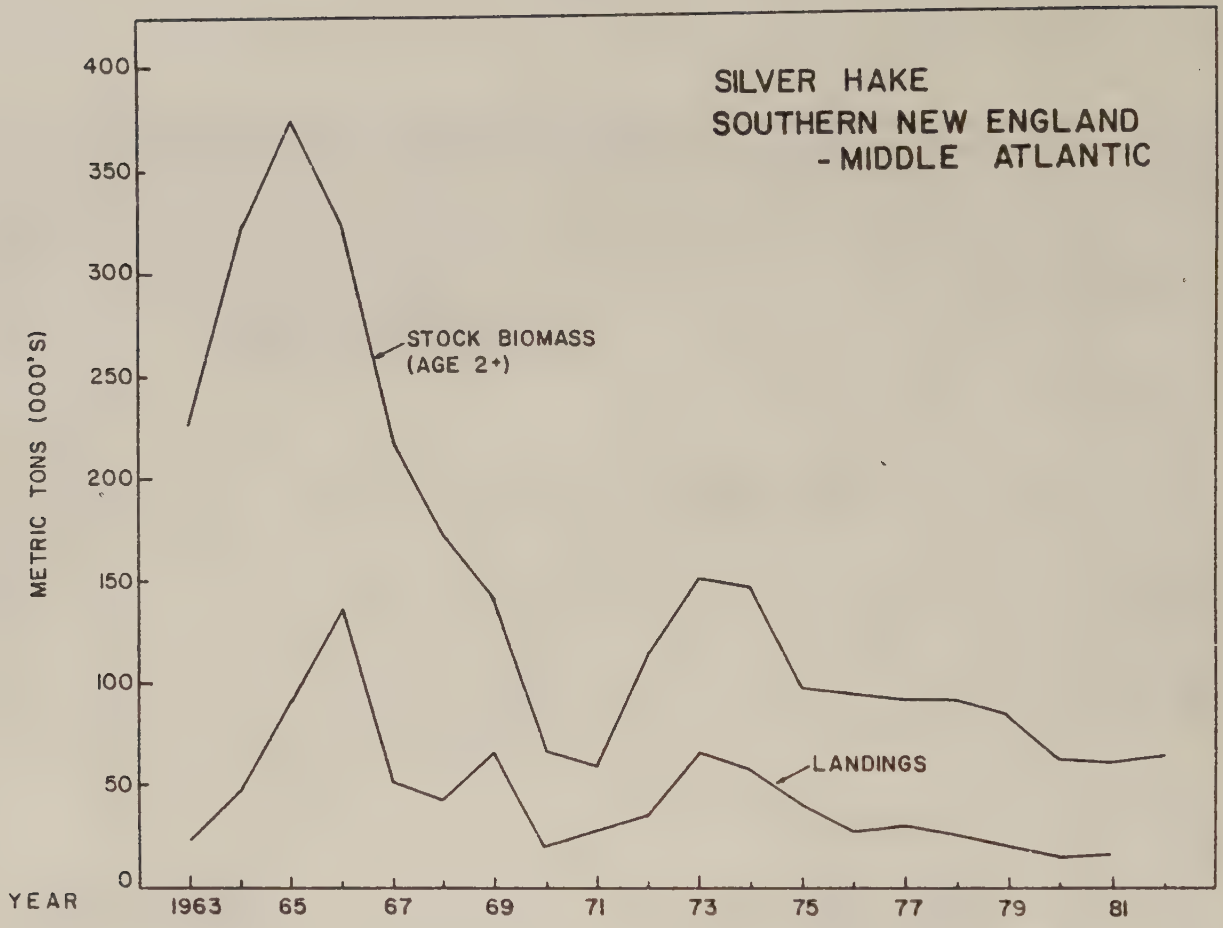

Fig. 9. Stock size and nominal catch of silver hake in the Southern New England - Middle Atlantic area.

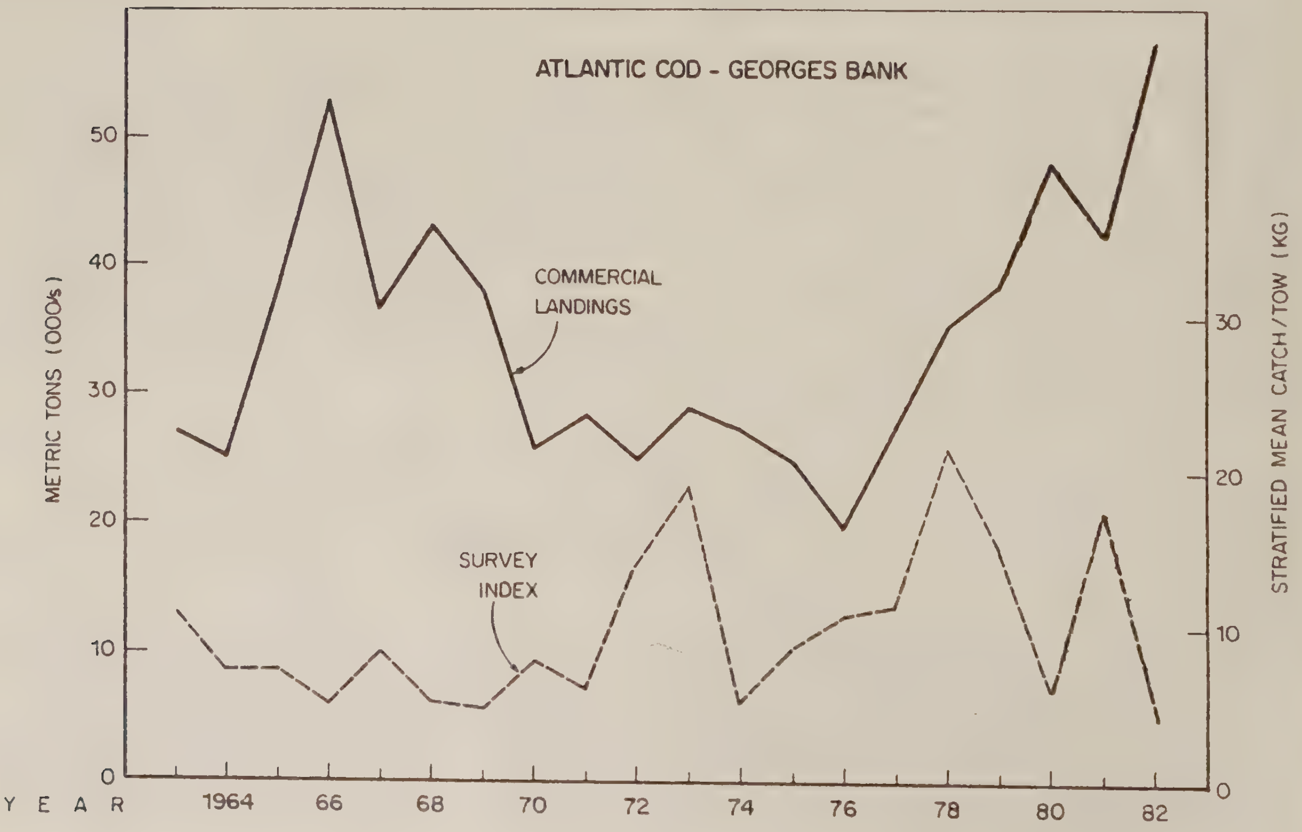

Fig. 10. Biomass index and nominal catch of Atlantic cod on Georges Bank.

All three stocks were at high levels of spawning biomass in the early 1960's with the Gulf of Maine being at its highest in the 1950's (Almeida and Anderson, 1981a; Fig. 8), Georges Bank in 1964 (Fig. 9), and Southern New England - Mid-Atlantic in 1965 (Fig. 10). Recruitment patterns have been relatively similar in all three areas, with strong year classes in the early-mid 1960's, poor year classes in the late 1960's, an improvement in the early 1970's (not as strong as in the early 1960's), and rather poor year classes since. Fishing patterns differed in the Gulf of Maine from those in the offshore areas.

## Other Major Fish Predators

Cod, dogfish (primarily spiny dogfish, *Squalus acanthias*), and bluefish (*Pomatomus saltatrix*) comprise the major biomasses of fish predators other than silver hake. Cod over this period was a relatively stable stock consisting of several year classes. Cod abundance did decrease somewhat in the late 1960's after heavy fishing but later recovered to peak abundance at the present time (Fig. 10). The larger cod are especially significant in the proportion of fish that they consume. After the initial period of heavy fishing by distant water fleets the average size cod decreased and there were fewer larger cod present. Cod also became more restricted in the extent of their winter southerly migrations. With the recovery of the cod stock the larger fish have become more abundant and the range is again extending further south in the winter. Strong year classes produced in the middle to late 1970's fueled this rebuilding (Serchuk et al., 1982a; Resource Assessment Division, 1982). The cod catch is presently above 60,000 tons and stock biomass is probably on the order of 150,000 tons.

Dogfish and bluefish increased in the early 1970's during a period when other stocks were at low ebb (Figs. 11, 12). High population levels continued throughout the late 1970's and early 1980's. There is no estimate of biomass of bluefish, however, estimated catches of bluefish reached highs of 50,000 tons in recent years (Resource Assessment Division, 1982). Minimum dogfish biomass has been estimated from areal expansion of annual trawl survey catches. Recent estimates are about 500,000 tons in 1980 (Resource Assessment Division, 1982). This is more than double the biomass of the early period.

Cod occur mainly in the Georges Bank and Gulf of Maine areas except for winter migrations to the south. Dogfish are a migratory species which move into the Mid-Atlantic in the winter and into the Gulf of Maine-Georges Bank areas in the summer, with some dogfish moving as far north as Newfoundland. Bluefish are a migratory species which move south of Cape Hatteras in the winter and north along the coast as far as the southwestern part of the Gulf of Maine, where an intensive summer recreational fishery takes place in inshore areas. However, bluefish also move out into Georges Bank in the summer.

## Squid

There are two abundant squid species off the coast of the northeastern United States, and they are both commercially important. These are the long-finned or winter squid, *Loligo pealei*, and the short-finned or summer squid, *Illex illecebrosus*. Both species are active predators, feeding on fish and other squid at various times in their short life cycle of 1-2 years. Squid are also the prey of over 40 fish species and several marine mammals.

The long-finned squid ranges primarily between Cape Hatteras and southern Georges Bank and rarely occurs in the Gulf of Maine. This species moves inshore during the late spring and summer to spawning grounds, and in the late autumn and winter is concentrated off-shore from 200 to 400 meters.

The short-finned squid ranges from Florida north to Newfoundland. The species concentrates in the offshore areas in the southern portion of its range in the winter, and moves inshore (including the Gulf of Maine) and northward in the summer to feed. Spawning takes place in the offshore areas, although exact locations have not been found. Maturing individuals are seen in December (Lange and Sissenwine, in press).

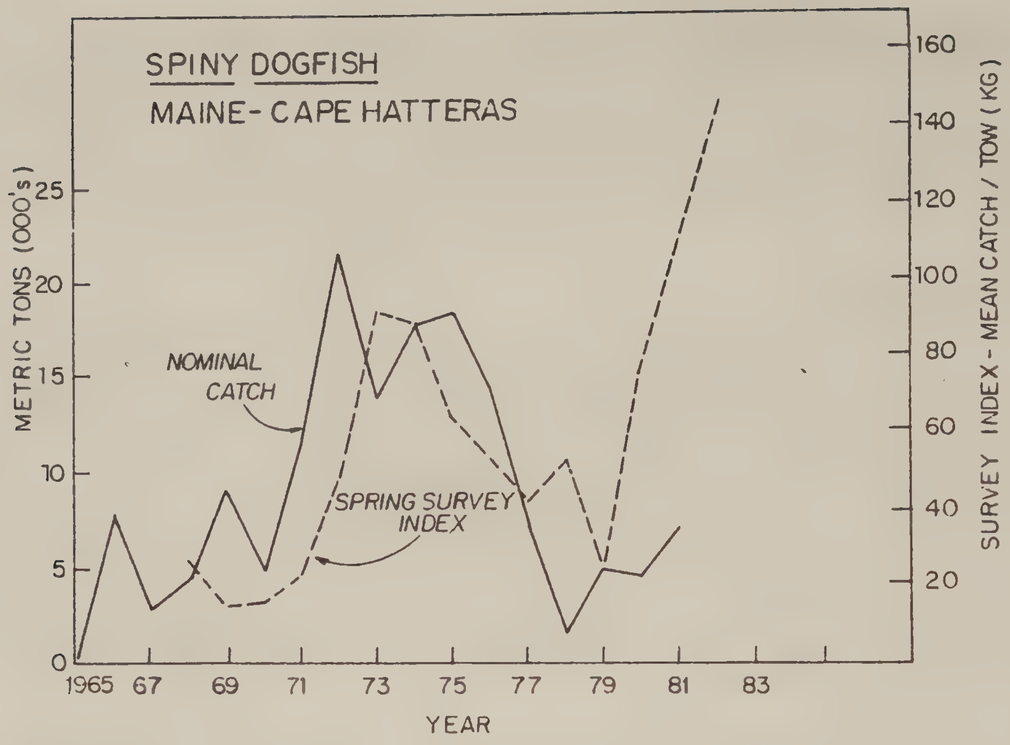

Fig. 11. Biomass index and nominal catch of spiny dogfish in ICNAF/NAFO Subareas 5 and 6.

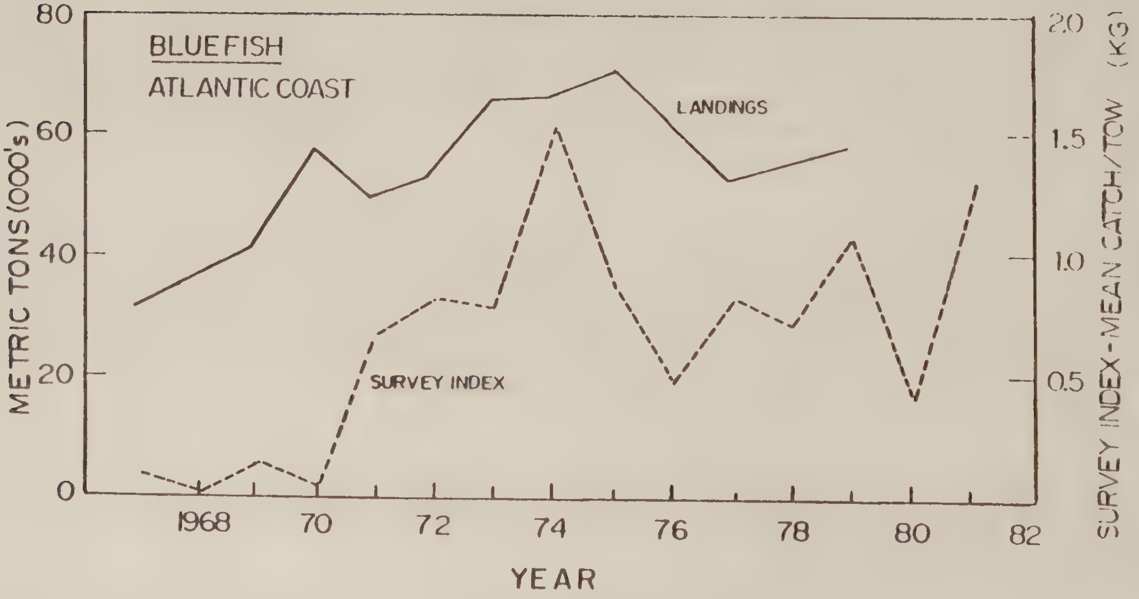

Fig. 12. Biomass index and nominal catch of bluefish along the Atlantic coast of the United States.

In the early 1960's there were apparently relatively few *Loligo*, although information on them is not very complete for the years before 1969. Beginning in 1969 and continuing into the early 1970's, there was a large increase in the abundance of *Loligo*. The commercial fishery developed beginning strongly in 1969, and reached peak catches of almost 38,000 tons in 1973. Since the extension of coastal state jurisdiction catches declined to a low point in 1978 of about 11,000 tons with reduced effort. However, catches have since risen to over 20,000 tons as the United States has expanded its fishery. Research survey indices, although fluctuating, have remained relatively high since 1968. Minimum biomass estimated from trawl surveys was estimated to be approximately 150,000 tons in autumn, 1982. (Lange, 1982; Fig. 13).

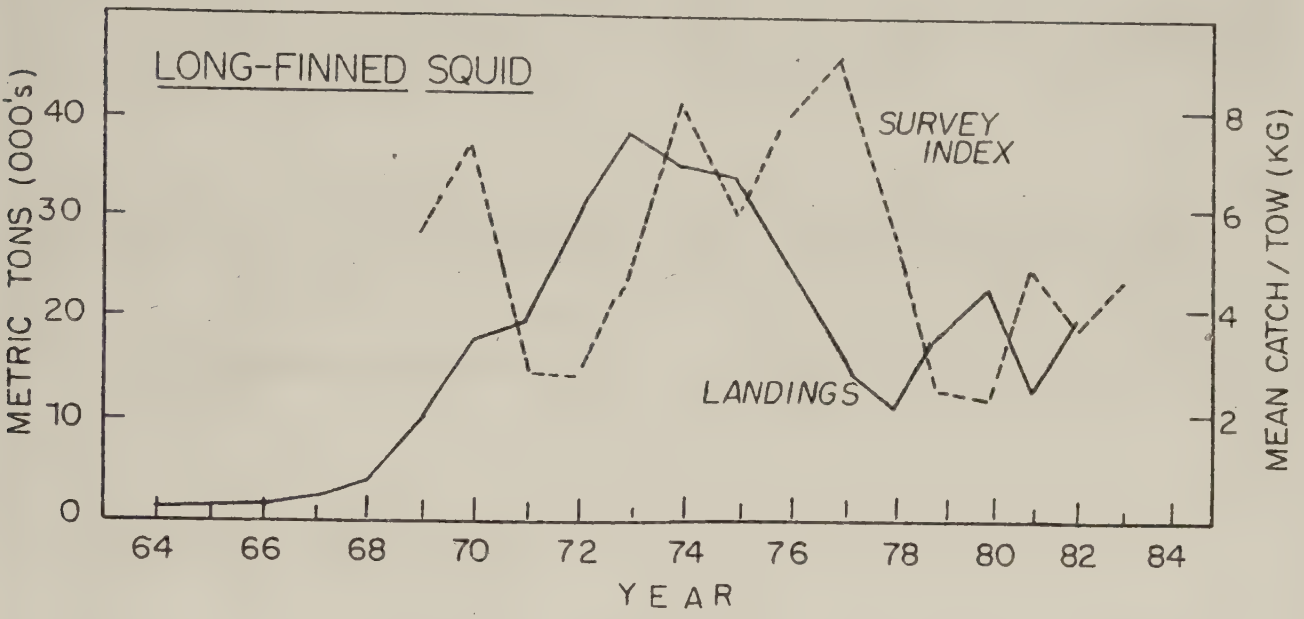

Fig. 13. Biomass index and nominal catch of long-finned squid in ICNAF/NAFO Subareas 5 and 6.

*Illex* squid are not monitored as well by the research surveys as *Loligo* because they are more pelagic and are partially located outside of the areas surveyed during the survey periods. Nevertheless, both survey indices and increased commercial catches indicated a very great increase in abundance soon after the *Loligo* population began its increases in the early 1970's (Fig. 14).

*Illex* squid catches off Canada reached a high of 150,000 tons in 1979, but have dropped sharply since then. Abundance off the United States appears to remain high although the 1982 survey indices were the lowest since 1974. Given the variability of *Illex* catches it is not possible to draw a conclusion at this time as to whether or not a downward trend has started (Lange, 1982). The increase in the biomass of these two species of squids was a major factor in maintaining a greater stability in total biomass than for individual species, as squid filled some of the total biomass void vacated by Georges Bank herring, and to some extent, mackerel.

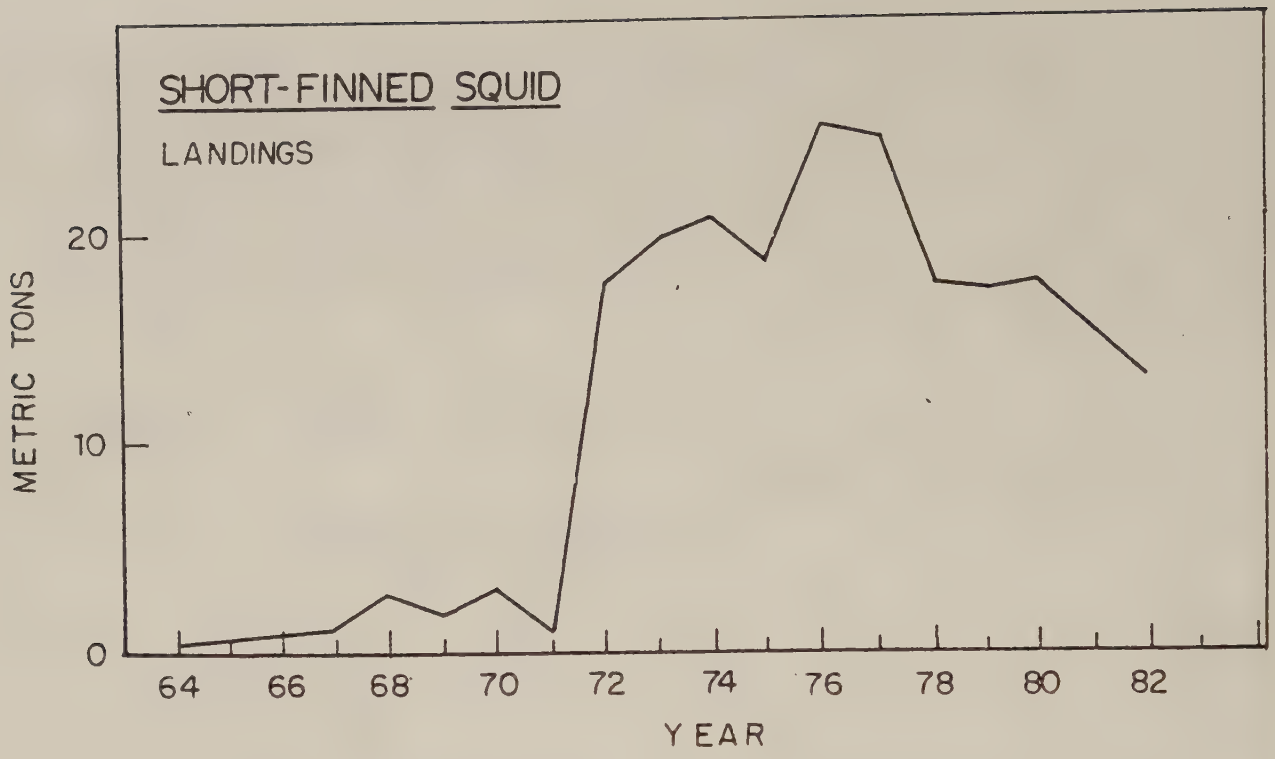

Fig. 14. Nominal catch of short-finned squid in ICNAF/NAFO Subareas 5 and 6.

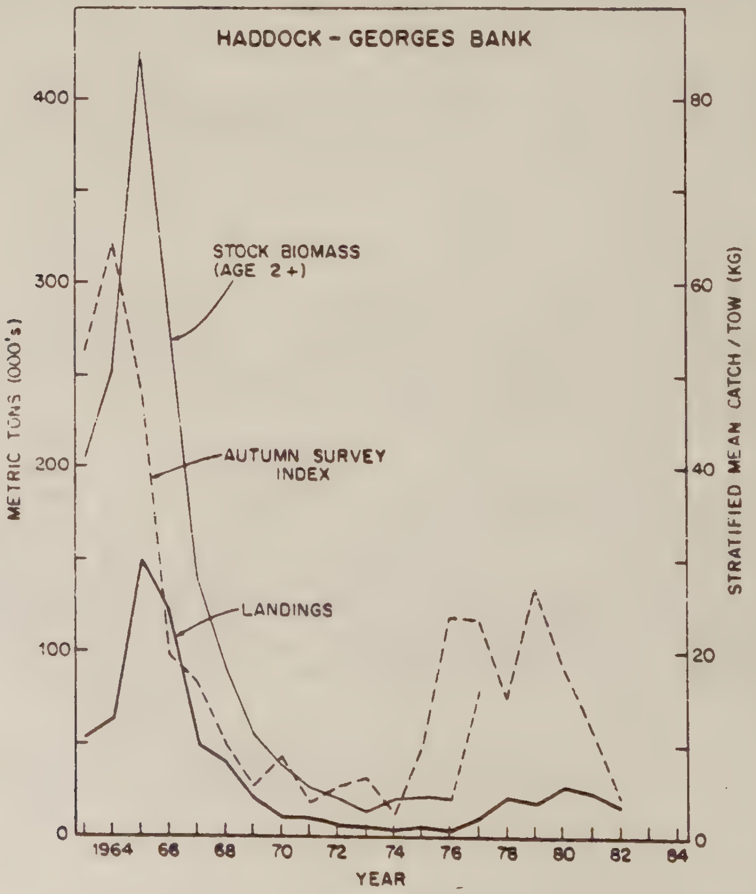

Fig. 15.
Stock size and nominal catch of haddock on Georges Bank.

## Other Resources

Haddock was initially a major component of the Georges Bank-Gulf of Maine fishery with a long-term sustainable annual harvest between 50,000 and 60,000 tons. It has a short spawning season in the late spring and its young form concentrated schools which are vulnerable to predator fish. The haddock population on Georges Bank exploded with an extremely large 1963 year class. Heavy fishing quickly reduced haddock to very low levels, which was followed by a long period of very poor production of year classes. Haddock increased slightly under extremely restrictive fishing regulations. In 1975 a fortuitous circumstance took place and a large year class was produced from a very low spawning stock. In the following two years, still with a small spawning stock, small year classes were produced. In 1978 the spawning stock had increased significantly with the maturing of the 1975 year class and another large year class was produced. Heavy fishing by US fishermen in the late 1970's and early 1980's drastically reduced the 1975 and 1978 year classes so that by 1982 haddock was decreasing again. Since the 1978-82 year classes appear poor, haddock appears to be headed toward very low levels of population size (Clark et al., 1982a, b; Fig. 15).

A large number of miscellaneous groundfish species (e.g., red hake (*Urophycis chuss*), ocean pout (*Macrozoarces americanus*), wolffish (*Anarhichas lupus*), white hake (*Urophycis tenuis*), pollock (*Pollachius virens*)) have been significant components of the trawl fisheries. These stocks in general followed a pattern of high abundance in the early 1960's, decreasing abundance during the period of intense distant water fleet fishing and rebuilding in the late 1970's (Clark and Brown, 1977). Some species such as pollock (Clark et al., 1981a) have recovered much faster than others such as red hake (Almeida and Anderson, 1981b). Flounders are another important component of this ecosystem and consist of several sepcies (e.g. winter flounder (*Pseudopleuronectes americanus*), yellowtail flounder (*Limanda ferruginea*), American plaice (*Hippoglossoides platessoides*), and witch flounder (*Glyptocephalus cynoglossus*)). These species in general followed the same pattern as the other groundfish, with yellowtail flounder, however, reaching its peak in the late 1960's and dropping drastically after experiencing heavy fishing and thus having a slower recovery than the other flounder stocks which were harvested to a lesser degree (McBride et al., 1980; Clark et al., 1981b).

Other pelagic species contribute significantly to the total biomass. Butterfish (*Peprilus tricanthus*) and scup (*Stenotomus chrysops*) are primarily Middle Atlantic-Southern New England species that have an inshore northerly summer migration and over-winter offshore in the Middle Atlantic. These species decreased during the period of heavy offshore fishing and have since increased somewhat (Waring and Anderson, 1981; Mayo, 1982).

In the spring, alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) return to the sea following spawning in rivers along the middle and southeast coast of the US; some travel north to Georges Bank and beyond. In addition, river herring from tributaries to the Gulf of Maine and southern New England also contribute to the offshore resources. These species decreased during the 1960's and 1970's with offshore harvest adding to the decline in production in the southern rivers. Populations in total are still below earlier levels but there has been some indication of rebuilding from increased catches offshore in trawl surveys (Resource Assessment Division, 1982).

## Ammodytes sp.

During the period of reduced biomass of those species harvested commercially as described previously in this paper (1974-79), scientists at the Northeast Fisheries Center's Sandy Hook Laboratory found evidence of a significant change in the ichthyoplankton structure when they discovered a large-scale increase in larval sand lance abundance during winter Marine Resources Monitoring, Assessment and Prediction surveys (MARMAP). (See Sherman (1980) for a detailed description of the program.) Abundance estimates of *Ammodytes* sp. larvae increased 20-fold from 1974, when they accounted for less than 50% of the winter larval assemblage, to 1979, when they accounted for nearly 90% of the winter ichthyoplankton (Sherman et al., 1981). The increase in larval abundance and evidence of population increase from other studies (e.g. bottom trawl surveys, diver observations, and a significant increase in *Ammodytes* sp. in predator stomachs) indicate that adult populations increased sharply after 1976.

*Ammodytes* larvae were captured at over 61% of stations occupied during 18 MARMAP surveys conducted by the NEFC between the Gulf of Maine and Cape Hatteras during 1974-80. Back-calculated numbers at hatching ranged up to 77,000 per $10m^2$ with the highest densities occurring on Georges Bank and from Nantucket Shoals to Long Island (Sherman et al., 1981). Mean catch per tow was lowest in 1974 at 153.4 larvae per $10m^2$, and highest in 1977 at 6,544.4 larvae per $10m^2$. Spawning stock estimates based on egg survival between 1.0% and 0.05% increased 50-fold between 1974 and 1978 and then decreased in 1980 to approximately one-third of the 1978 level (Table 2; Morse, 1982). Incubation time for *Ammodytes* sp. eggs is unusually long, greater than 30 days (Laurence[2]), which suggests a potential for high egg mortality. If daily mortality is 5% for 30 days, then survival is only 22% to hatching; for 45 days survival is 10%. Assuming egg survival at the 0.10 level (e.g., similar to Atlantic herring egg mortality estimates) the estimated spawning stock biomass in 1980 was 917 thousand metric tons (Table 2).

Table 2: Spawning stock estimates of sand lance, *Ammodytes* sp., in metric tons from Georges Bank to Cape Hatteras, 1974-1980. $\bar{X}$ is mean catch per tow and Z is larval mortality coefficient.

| Year | Survey | $\bar{X}$/Tow | Std Error of $\bar{X}$ | Z | Egg Survival | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1.00 | 0.90 | 0.75 | 0.50 | 0.25 | 0.10 | 0.05 |
| 1974 | 1 | 153.4 | 43.136 | 0.221 | 5,489 | 6,099 | 7,318 | 10,978 | 21,956 | 54,890 | 109,780 |
| 1975 | 1 | 528.1 | 155.130 | 0.207 | 25,547 | 28,386 | 34,063 | 51,094 | 102,188 | 255,470 | 510,940 |
| 1976 | 1 | 4,541.6 | 1,254.084 | 0.308 | 207,717 | 230,797 | 276,956 | 415,434 | 830,868 | 2,077,170 | 4,154,340 |
| 1977 | 1 | 6,544.4 | 2,452.655 | 0.283 | 246,333 | 273,703 | 328,444 | 492,666 | 985,332 | 2,463,330 | 4,926,660 |
| | 2 | 188.0 | 94.622 | | | | | | | | |
| 1978 | 1 | 6,321.4 | 2,022.060 | 0.363 | 264,141 | 293,490 | 352,188 | 528,282 | 1,056,564 | 2,641,410 | 5,282,820 |
| | 2 | 584.0 | 324.004 | | | | | | | | |
| 1979 | 1 | 3,239.4 | 1,257.670 | 0.288 | 196,432 | 218,258 | 261,909 | 392,864 | 785,728 | 1,964,320 | 3,928,640 |
| | 2 | 1,197.8 | 260.543 | | | | | | | | |
| 1980 | 1 | 1,171.6 | 361.523 | 0.229 | 91,764 | 101,960 | 122,352 | 183,528 | 367,056 | 917,640 | 1,835,280 |

## HYPOTHESIZED INTERACTIONS

### Mackerel-Herring Interactions

One of the most intriguing aspects of the changes in fish population abundance and fisheries in the Northwest Atlantic during the past 25 years has been the shift of the major pelagic species from herring to mackerel. A simplistic circumstantial conclusion would be that mackerel replaced herring in the ecosystem. Since the passage of the good 1966-69 year classes through the stock, mackerel has returned to mid-1960's abundance levels. The herring stock on Georges Bank, however, has not recovered at all and is virtually nonexistent, although the herring stock has recovered in the Gulf of Maine and is still at modest abundance levels in the stocks off southwestern Nova Scotia.

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[2] Geoffrey C. Laurence, NEFC, Narragansett Laboratory, Narragansett, RI, personal communication.

Skud (1982) examined the historical herring-mackerel interaction from recorded catch statistics and earlier reports of catches dating back to the early 1800's and attempted to relate this to environmental factors. He noted that during much of the 1800's mackerel were more abundant than herring. Following a collapse of the mackerel fishery in the late 1880's herring became more abundant, declined in the 1930's, and greatly increased in abundance during the 1940's and 1950's. He noted that herring abundance was positively correlated with temperature when herring were more abundant than mackerel, but negatively when mackerel was more abundant or when the population was shifting. Likewise mackerel was negatively correlated with temperature when herring was abundant and positively when mackerel dominated. This evidence, however, still remains circumstantial because there is no specific biological rationale to indicate the cause of this interrelationship. Furthermore, mackerel did increase in the 1930's due to entry of good year classes when herring abundance apparently declined. Mackerel abundance might have exceeded herring during that brief period of time even though catches were lower. Mackerel collapsed in the 1940's and herring, as noted in the Gulf of Maine juvenile fisheries, increased greatly in abundance at that time. It should be noted that the herring catches over this period of time did not include the Georges Bank and Nova Scotia adult populations for which little information was available and thus primarily reflect populations in the inshore Gulf of Maine areas. In the late 1960's when the Georges Bank stock was at its maximum the mackerel stock was increasing and the very good 1967 year class was produced. It should also be noted that in the late 1880's a period of extremely successful mackerel year classes caused a large increase in the mackerel fishery just prior to its collapse in the late 1880's. Despite the mystery that still surrounds the relative abundances and possible interactions of these two species, historical observations for over 100 years should lead fishery managers and scientists not to expect to see a co-occurrence of very high mackerel and herring biomasses.

It is difficult in recent times to separate the effects of natural factors on fish stocks from the effect of humans. However, one wonders what might have been the situation with regard to relative biomasses of herring and mackerel if the 1970 year class of herring on Georges Bank had been allowed to contribute to the population for a significant period of years. Year classes of even modest size coming from that spawning stock might well have resulted in herring and mackerel stocks relatively co-equal in size at the present time.

## Ammodytes--Herring--Mackerel Interactions

The dramatic 50-fold increase in the *Ammodytes* spawning stock biomass, following the precipitous decline in herring and mackerel stocks, indicates a significant change in the species composition of the pelagic finfish community. Clark and Brown (1977) estimated a 6-7 million ton decline in pelagic (primarily mackerel and herring) stocks from 1967 to 1975 in Subareas 5 and 6. Grosslein et al. (1980), estimated that average biomass on Georges Bank declined 42% and production of finfish and squid (Kcal/Km$^2$) declined by 26% from 1964 to 1975. Assuming the basic productivity of the shelf has not changed during the past 70 years based on studies by Sherman et al. (in press), then a surplus of food energy was available during the mid-1970's. *Ammodytes* biomass increased 30-fold from 1974 to 1976 indicating a shift in energy flow within the pelagic component of the ecosystem. *Ammodytes* abundance increased after the herring and mackerel stocks had reached extremely low levels which suggests replacement (Daan, 1980) as a causal mechanism rather than competition or predation (Fig. 16).

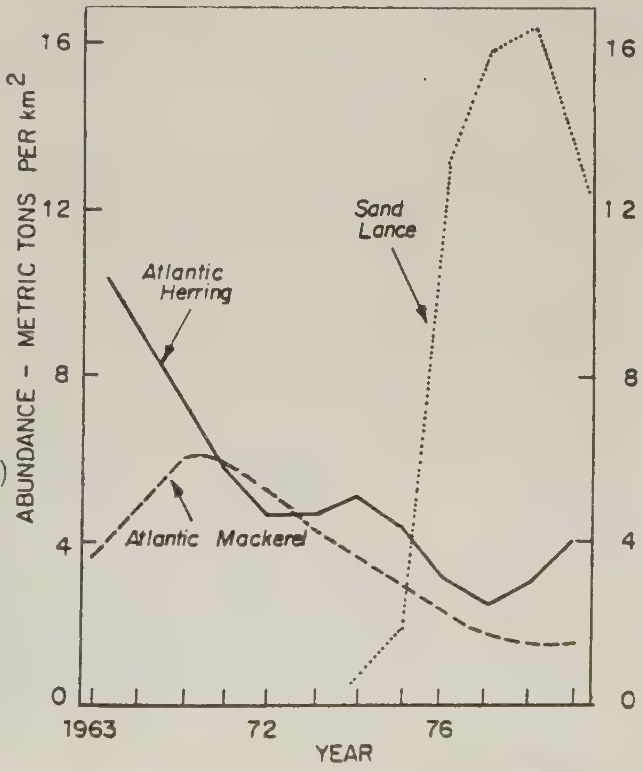

Fig. 16. Decline in herring and mackerel biomass in ICNAF/NAFO Subareas 5 and 6 and the successive increase in sand lance.

## Pelagic/Demersal Interactions

The most striking observation in examining the history of catches from the mid-1950's through 1980 in this region is that the catches of both pelagic and demersal species were modest with demersal species being somewhat higher. This was followed first by a large buildup and subsequent decline in catch of the demersal species. followed by a similar rise and fall in catches of the pelagic species (Fig. 17).

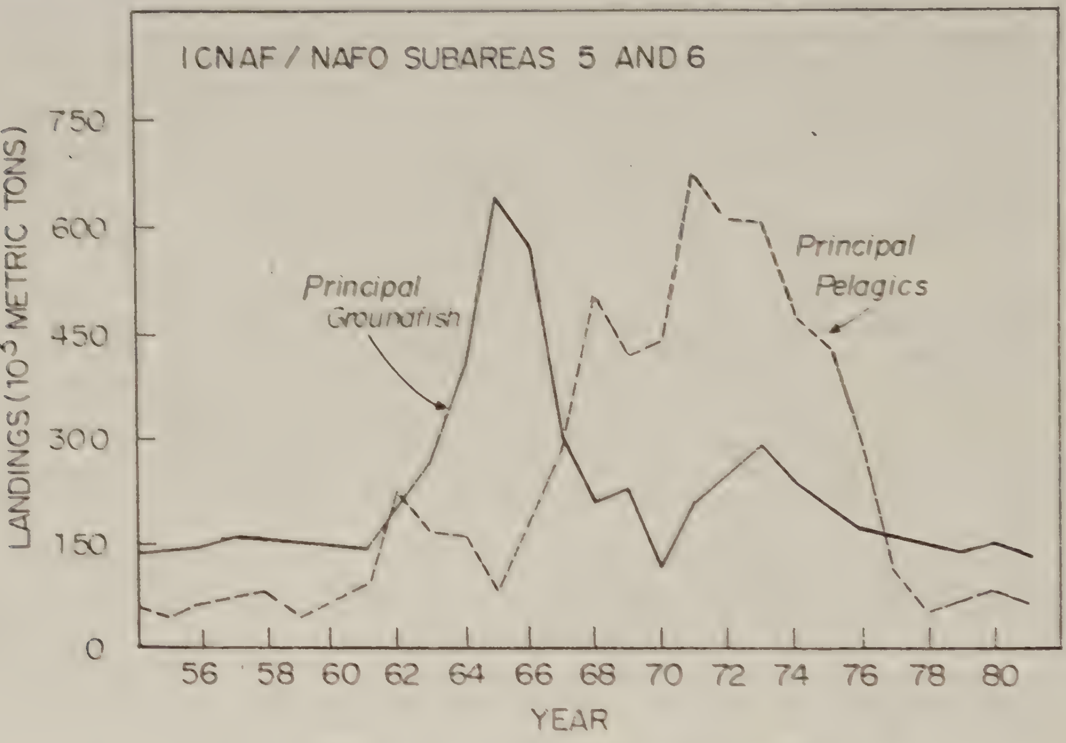

Fig. 17. Nominal catch of principal groundfish and principal pelagics in ICNAF/NAFO Subareas 5 and 6.

The figures here apply to the "principle" pelagic and groundfish as defined by ICNAF/NAFO, which means that the pelagics are primarily herring and mackerel; and the groundfish are primarily cod, haddock, silver hake, red hake, pollock, and redfish (*Sebastes marinus*). It should be noted, however, that miscellaneous other demersal species catches did build up in the latter part of the 1960's only to show a similar decline in the 1970's as discussed in the section on trends of total biomass. This substitution in the catches obviously kept the total up and it might appear as if pelagics replaced demersals in the ecosystem under the effects of heavy fishing pressure.

When this is examined a bit more closely one sees that these trends are driven by a relatively small number of extremely good year classes of haddock, silver hake, herring, and mackerel. If these four species were removed the picture would change drastically and and the peaks not exist.

While the pattern of rising and falling catches is certainly intriguing and suggests pelagic/demersal replacement, it is difficult to suggest biological hypotheses to support this when it can be seen that it was the result of herring year classes in 1960 and 1961, haddock in 1963, mackerel in 1966-69, and silver hake also in the early 1960's. These year classes were basically established either before or in the period between 6 months and one year of life based on the fact that indices at these times in the surveys (and in the case of herring in the fisheries) correlate strongly with estimated total year class strength.

In the Northeast Atlantic, specifically the North Sea, a different pattern emerged in which the pelagic species (mainly herring) declined first, to be replaced by increased productivity of demersals particularly Norway pout (*Trisopterus esmarki*). Jones and Richards (1976) indicated that the energy in the system released following the removal of the pelagic species could have provided the basis for the increase in demersals. The hypothesis that the North Sea might be a food limited area requiring the release of energy previously used by herring to allow a buildup in demersal species, is based on the energy budgets of Steele (1974) and Crisp (1975).

Grosslein et al. (1980) and Cohen et al. (1982) have estimated energy budgets for the Georges Bank area and concluded that this area is not food limited and, in fact, during the period they examined (the early 1960's to the mid-1970's) both demersal and pelagic species declined.

A review of fishing mortality rates estimated at various meetings of committees within the International Commission for the Exploration of the Sea (ICES) and at scientific committee meetings of International Northwest Atlantic Fisheries Commission (ICNAF) indicates that fishing mortality rates have been higher for principle groundfish species in the North Sea area than in the Northwest Atlantic. This decline of both groups cannot, therefore, be explained purely by a higher rate of removals in the Northwest Atlantic.

The picture which emerges is certainly not clear. Nevertheless, there does not appear to be any direct evidence or even strong circumstantial evidence for replacement between pelagic and demersal species in the southern area of the Northwest Atlantic.

## Stability of Total Biomass

Feeding habits of fish in this region indicate a potential for biological interactions (Fig. 18) based on both competition and predation. Brown et al. (1976) treated biological interactions implicitly by applying a surplus production model (Schaefer, 1954) to the aggregate catch of all finfish and squid (except menhaden, which are captured close to shore, and large pelagic species). Fishing effort by different gear types and nations was calibrated and combined to provide a standardized index of days fished. A learning function was applied to adjust fishing effort in newly developing fisheries. A sixfold increase in standardized fishing effort combined with a 55% decline in abundance in the period of 1961 to 1972 was demonstrated. This resulted in an estimate of maximum sustainable yield (MSY) in this region of about 900,000 tons, much less than the sum of the individual MSY's for species and species groups estimated at that time to be 1,352,000 tons. Brown et al. (1976) inferred that this difference in part reflected biological interactions and in part reflected difficulties in the methodology both in the estimate of the Schaefer yield curve and in the species estimates of MSY.

Sissenwine et al. (1982) modified the surplus production approach to include explicit consideration of biological interactions. They utilized 29 different species and tested all possible combinations for interaction. Of the 724 combinations examined, only 26 partial correlation coefficients were significant at the 5% level. Since less than 5% were significant, it must be concluded that the significant partial correlation coefficients were due to type 1 errors, that is chance alone. Sissenwine et al. (1982) also considered a time lag for those species which are fish predators. One hundred and ninety-nine combinations were fit with the results essentially being the same, about 5% significant at the 5% level. This empirical examination failed to demonstrate biological interactions. This result, however, does not necessarily imply that the biological interactions are unimportant, but only that an empirical approach is inadequate even when the data are as detailed as they are in this area, a combination of available data unlikely matched elsewhere for the same length of time. The most likely reason for the failure of this approach is the variability in recruitment and thus these empirical fits are not satisfactory for the same reasons that models of the stock and recruitment relationship fail to closely fit the observed data.

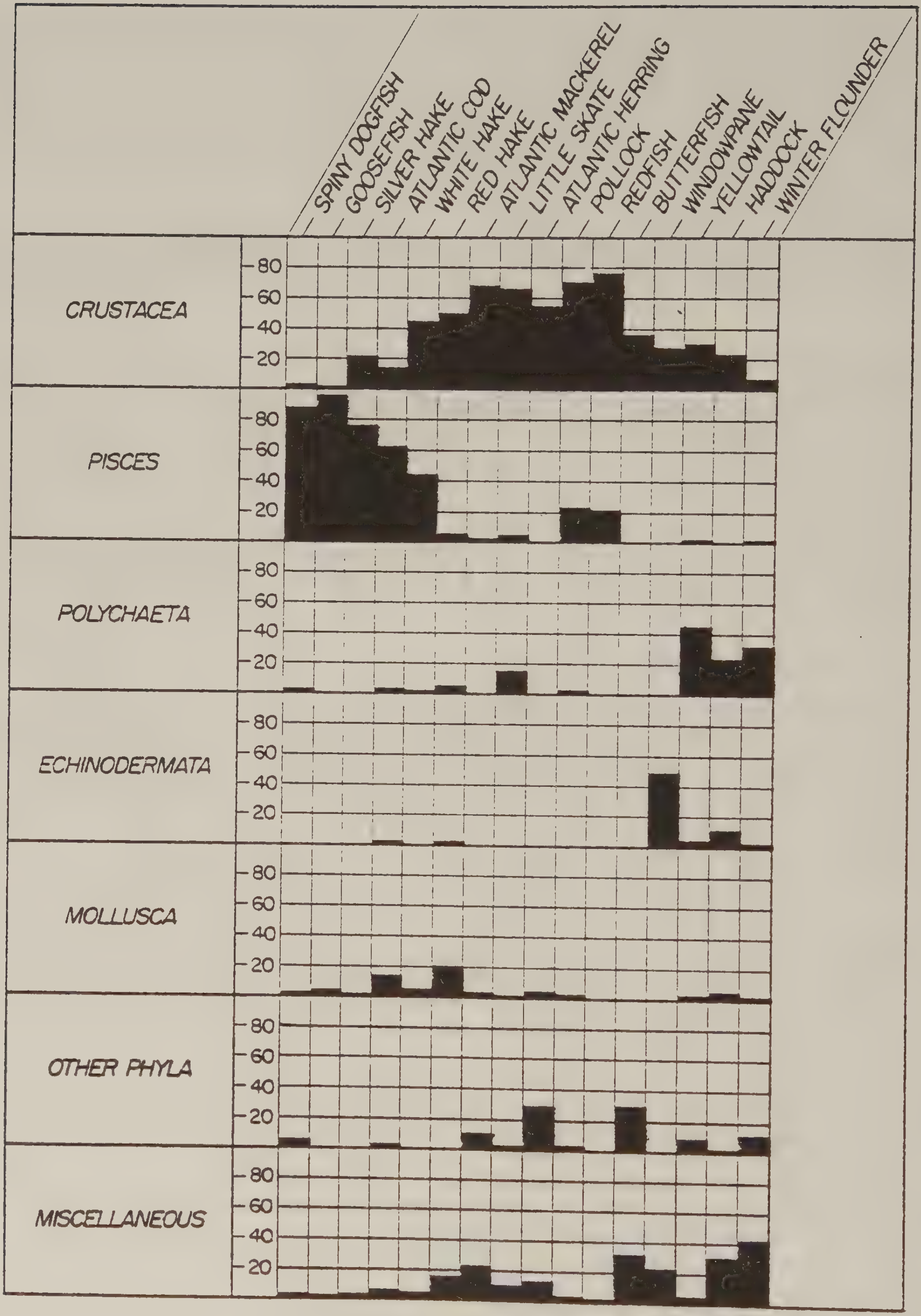

Fig. 18. Diagrammatic representation of the prey of sixteen species of fish collected on Georges Bank during 1969-72. Data are expressed as percentage weight (Grosslein *et al.*, 1980).

Foster (1982) utilized legion analysis (Pope, 1980) in a preliminary examination of a selected group of species on Georges Bank to estimate abundance and mortality. Although the overall conclusion of this preliminary analysis indicated that including the feeding interactions in these analyses did not greatly alter the conclusions drawn from cohort analysis of individual species, there were some significant indications of extensive feeding on the very early juvenile fish and thus a possibility that further analysis might be promising, particularly if a wider range of species could be included.

Despite the failure of the analyses of Sissenwine et al. (1982) and Foster (1982) to clearly demonstrate species interactions there is considerable circumstantial evidence for species interaction similar to that in the analysis of Brown et al. (1976). A plot of the catches on Georges Bank from 1955 to 1979 by species and total indicates a greater relative stability in the total compared to the individual species (Fig. 19; Hennemuth, 1979). Similar conclusions can be gathered from examining the trends in trawl survey estimates of population indices as illustrated in Clark and Brown (1977).

Sissenwine [3/] examined the variance of individual species catches from NAFO Subareas 5 and 6 during 1966-80 and compared the variance of the sum with the sum of the variances. He found the latter to be smaller than the former for the total catches of all species, but not for demersal species alone. Thus, the statistical evidence for stability rested with the herring and mackerel components.

## Environmental Interactions

The influence of temperature has been suggested as a principal factor in controlling abundance levels of fish stocks on the continental shelves of the Northwest Atlantic off the Canadian Maritimes and the northeastern United States (Dow, 1977; Sutcliffe et al., 1977). The reductions in abundance of herring and mackerel in both the Northeast and Northwest Atlantic in response to heavy fishing mortality, followed by increases in *Ammodytes* and other small, fast-growing fish (e.g., Fig. 16) do not support the hypothesis that the changes are due mainly to environmental factors as they are unlikely to be the same in both areas.

Zooplankton sampling for five years over an area of 260,000 km$^2$ on the continental shelf off the northeast coast of the US has indicated different seasonal pulses in abundance in four areas that are temporally coherent. Unlike the 30-year decline of zooplankton reported for the North Atlantic and North Sea, NEFC observations indicate that zooplankton off the northeast coast of the US has not undergone any large-scale change in abundance or species composition during the past 70 years. It appears that greater perturbations have been imposed on fish populations in this area by fishing mortality than from any changes in the abundance levels of zooplankton (Sherman et al., in press).

## RECRUITMENT AND ESTABLISHMENT OF YEAR CLASS STRENGTH

Recruitment is the major source of uncertainty in all of the major fisheries that have been discussed in this paper. Recruitment is affected by both the biotic and abiotic environment. Obviously, at some level there has to be a relationship to stock size. Much effort in fisheries research has gone into examining the relationships between stock and recruitment. The early pioneering work was done by Ricker, Beverton and Holt. The basic discussion can be found in their texts (Beverton and Holt, 1957; Ricker, 1958). Attempts have been made to fit relationships between stock and recruitment for most of the stocks of the Northwest Atlantic. None of these have proven statistically satisfactory. Realizing that only very minor changes in the survival in the early life history stages can cause very large differences in the number of survivors to adult sizes, it is not surprising that there is great variability about any stock recruitment function and attempts to use such a function as a predictor are not satisfactory over a wide range of

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[3/] Michael P. Sissenwine, NEFC, Woods Hole Laboratory, Woods Hole, MA, personal communication.

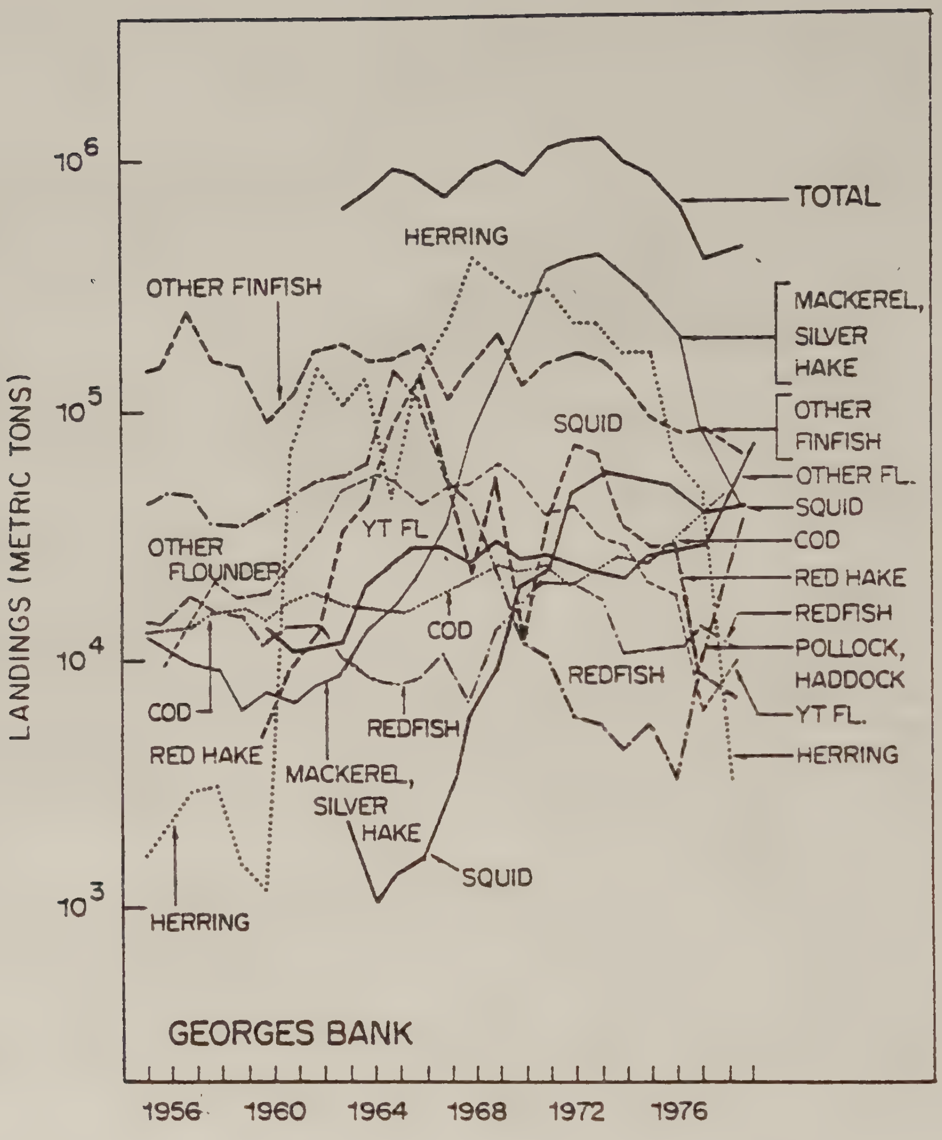

Fig. 19. Nominal catch for total and major species on Georges Bank, 1955-79.

stock biomasses. Frequently, advice to fisheries managers is that over a wide range of stock sizes above some minimum, recruitment can be viewed as varying independently of stock size.

Hennemuth et al. (1980) examined recruitment in 18 fish stocks for which they could obtain data and fit statistical distributions functions to these numbers. The stocks they examined included several in the Northwest Atlantic. In general, a lognormal distribution describe these stock recruitment observations. Further efforts to refine the statistical fitting procedures have been produced by (Taille and Patil, 1982). In almost all cases such distribution functions need to account for infrequent occurrence of very large year classes, a modal group consisting of much smaller year classes and with a few year classes being very small. The latter is most obvious in very heavily fished stocks with reduced spawning stock biomass. These data would suggest that the real problem in fishery prediction is understanding the occurrence of the very large year classes which, historically, have been observed to drive fisheries.

Serial correlations between adjacent years recruitment estimates were found by Hennemuth et al. (1980) indicating that in most cases, recruitment in one year correlated significantly with that of the previous year. However, this does not hold true for the occurrence of the very large year classes. Serial correlations are not surprising if recruitment is related to stock size which tends to be similar in adjacent years or to climatic conditions which also tend to be serially correlated.

Although certain forms of stock recruitment relationships, particularly those developed by Ricker (1954) indicate a negative effect of a very large spawning stock size, this has not been conclusively observed for the species discussed here in the Northwest Atlantic or for similar species in the Northeast Atlantic. On the other hand, there have been strong indications that at very low spawning stock sizes there is a reduction in the number of large year classes and an increase in the proportion of very small year classes although cause and effect are not clear given the paucity of data and its confounding with the lack of independence of adjacent years observations. Thus, there is a concern to provide advice to managers of stock sizes which cause potential problems. Sometimes this has been done empirically as for mackerel, in which case scientists recommend, because of the lack of specific information, that stock sizes not be reduced below those that existed prior to the production of the large year classes. From a practical standpoint this did prove to be a stock size from which in later years the mackerel stock began to rebuild. However, there is no evidence to indicate that the stock would not have begun to rebuild even if stock size had been driven to a lower level prior to the reduction of fishing effort.

Shepherd (1982) described a generalized stock recruitment relationship, which by varying parameters can represent non-asymtotic, asymtotic, and dome stock recruitment relationships but more importantly addressed its practical applications. From the practical management standpoint he suggested that given the data available that the fits of the critical parameters could be just as accurately obtained from crude procedures as from sophisticated nonlinear curve fitting. Shephard states that the important question is the left hand slope of the line where according to stock recruitment hypotheses average recruitment would drop rapidly as stock size decreased. This left hand limb can be determined by drawing a straight line through the origin just to the left of the bulk of the data available. The slope of this line gives the parameter a of Shephard's stock recruitment function and allows the estimate of the left hand limb. This was done for the North Sea herring and provides a practical way of obtaining a minimum spawning stock size to recommend to managers.

A variation of the stochastic approach of Hennemuth et al. (1980) would assign probabilities to given levels of recruitment by segmenting the data into components of stock size groups and calculating probabilities of recruitment size for different ranges of spawning stock sizes. However, frequently the data bases are too small to allow such analyses.

Brown and Halliday (1983) reviewed the observed recruitment/population trends for a number of stocks in the Northwest Atlantic here and indicated that in a number of cases there was circumstantial evidence of lower recruitment from low stock sizes. This was observed not only for Georges Bank haddock where only one strong year class occurred during a long period of low spawning stock sizes under a wide variety of environmental conditions but for other stocks as well. For herring, no year class of any strength has recruited to the Georges Bank since 1970 during a period when the spawning stocks. except for 1974, were considerably below ( 1/10) those of the early 1960's. In contrast to Georges Bank, however, the Gulf of Maine spawning stock rebuilt in 1974 and, although subsequently reduced by fishing, did not reach extremely low levels (it stayed above 1/5th of 1960-70 peaks) and strong year classes were produced in 1976, 1977, and 1979. The present contrast is that the herring stock in the Gulf of Maine is in a robust condition while the Georges Bank spawning stock, fished to very low levels, has suffered complete collapse.

Silver hake similarly shows such a contrast. The Georges Bank stock, now less than 10% of the 1960's, has been producing only poor year classes since 1970 while in the southern New England - Middle Atlantic silver hake spawning stock, now about 20% of its peak in 1965, has been producing year classes significantly larger than those on Georges Bank. The mackerel stock as discussed earlier was stabilized at about 20% of its peak size and has initiated a recovery trend.

Except for the question of the very small stock sizes examination of stock recruitment relationships has not been of help in understanding year class variability. This multispecies recruitment problem was identified within the Northwest Atlantic as the most important scientific problem more than two decades ago (Galtsoff, 1962).

Statistical studies such as Sissenwine's (1977) study of yellowtail flounder have been used to relate environmental conditions to recruitment. However, like spawning stock size, environmental correlations tend not to be precise predictors and often do not hold up over time. Thus, evidence is accumulating that recruitment is probably a multiplicative function of a highly variable process occupying various life stages during the first year of life.

Traditionally, fisheries ecologists have hypothesized that variability in year class strength reflects relatively small changes in very high mortality rates during the ichthyoplankton stage and thus have focused on the earlier life history stages. Extensive programs have been carried out in the Northwest Atlantic, both field surveys and experimental studies. Recently, Sissenwine et al. (in press) demonstrated that on Georges Bank predation by a few key predators (e.g. silver hake and cod) probably results in high postlarval fish mortality. Furthermore, preliminary examination of larval abundance data and estimates of egg production in relation to recruitment indicate mortality at the late larval and postlarval stages of several Northwest Atlantic species (e.g. Georges Bank haddock, herring) is of equal magnitude to mortality rates of eggs and larvae. Furthermore, virtually none of the variability in year class strength has been explained by the abundance of larvae. Thus the evidence however limited points to the postlarvae and early juvenile period where the effects of predation can be expected to be significant to be critical to the determinations of year class variability as observed at juvenile 1-2 year ages.

## DISCUSSION

During the past 25 years, fisheries in NAFO Subareas 5 and 6 responded to the occurrence of strong year classes. The 1960 and 1961 year classes of herring established the abundance on which the offshore fishery developed. A very large 1963 year class of haddock attracted additional US and Canadian effort and new USSR effort. Given the mixed species nature of bottom trawl fisheries, this resulted in increased mortality to cod and other demersal species. The distant water fleets (primarily the USSR) next turned to silver hake which was highly abundant as a result of strong year classes which entered the population in the early 1960's (the exact years differ between stocks). The silver hake fishery used small mesh nets fishing on or close to the bottom which were capable of catching demersal fish as young as age 1, in contrast with the traditional US and

Canadian trawl fisheries which used larger mesh, most effective for demersal species 2.5 years and older. As a result of the small mesh, the silver hake fishery contributed significantly to mortality in young fish of many species. After the silver hake fishery developed the next major resource subjected to greatly increased fishing pressure was mackerel, where the large 1966 and 1967 year classes attracted the distant water fleets.

The direct effect of fishing on these resources is relatively easily measured. The larger year classes that attracted these increases in effort would have sustained populations of considerably larger size for much longer periods of time had removals been kept at modest levels. There is no question that if fisheries managers desired a more stable catch and catch per unit effort, a moderate fishing level would have achieved that goal for the above resources.

The question, however, obviously arises whether the extremely heavy fishing pressure with its depression of spawning stock size had any effect on the length of time between strong year classes. The evidence is inconclusive. Nevertheless, as pointed out earlier in the species discussions and in the stock recruitment section, there is strong circumstantial evidence for the effect of reduction in biomass to extremely low levels (less than 20% and in some cases lower than 10% of peak abundance levels) being followed by less frequent occurrence of strong year classes.

In addition to the single species effect of fishing, either directly on the fishery resource yields or on future recruitment, there is the multispecies question. The evidence for a multispecies relationship again is both circumstantial and difficult to explain biologically. Nevertheless, the circumstantial evidence points to a greater stability in total biomass than in individual species, particularly when the pelagic species are considered. It also points to maintaining high levels of total biomass through shifts from originally herring, to mackerel, to squid and then to *Ammodytes*. There has been an increase in recent years of dogfish and bluefish after a decline in silver hake, resulting in total fish predators maintaining a relatively stable total predatory biomass. This shift has had a qualitative change toward predators able to feed on larger fish. The mackerel-herring substitution appears not only in this recent period, but there is some indication of similar situations in the past century as discussed in the review of Skud's (1982) paper. However, this must still be considered circumstantial as no biological hypothesis can yet be substantiated.

Attempts to find environmental correlates that hold true over time have not yet proven very successful. Yet, like the multispecies interactions, there are obviously relationships. The lesson here is that these relationships are difficult to hypothesize and interpret based on empirical data, just as there has been failure to date to directly demonstrate multispecies interactions.

The strongest lesson learned to date is the importance of looking at the total fishery resource ecosystem to the fullest extent possible, and understanding the wide variability that is normal. Table 3 and Figure 20 summarize the current and historical biomass conditions for major Northwest Atlantic fisheries (Serchuk et al., 1982b). This figure also indicates where in the current judgement of the Northeast Fisheries Center's fishery scientists concern should be expressed about low stock sizes relative to the immediate future productivity of these resources, as well as indications where evidence exists for low spawning stock sizes having actually had an effect on this productivity. Several general, but important, relationships are discernable from this summary.

1. For most all stocks the maximum observed biomass is generally no larger than four to five times the median, while the lower observed level may be proportionally much lower...often as low as 5 to 10 percent of the median. This pattern suggests that biological and ecological factors probably constrain the upper limit of stock biomass, but that exploitation can have a marked effect at reducing stock levels to their lowest bounds.

Table 3: Summary of current and historical biomass conditions for major Northwest Atlantic fisheries resources.

| Stock | Biomass | | | Current value | Biomass units | Index | Primary data source | Current Fishery Management Status |
|---|---|---|---|---|---|---|---|---|
| | Median | Maximum | Minimum | | | | | |
| Gulf of Maine Haddock | 8.2<br>(1963-1981) | 33.6<br>(1963) | 2.0<br>(1972) | 7.8<br>(1981) | kg/tow<br>(0+) | Autumn survey | Clark et al. 1982a | Managed under Fishery Management Plan (FMP) |
| Gulf of Maine Cod | 9.4<br>(1963-1980) | 14.1<br>(1964) | 4.2<br>(1976) | 13.1<br>(1980) | kg/tow<br>(0+) | Autumn survey | Serchuk et al. 1982a | Managed under FMP |
| Gulf of Maine Silver hake | 75<br>(1955-1981) | 194<br>(1955) | 16<br>(1971) | 30<br>(1981) | $10^{-3}$tons<br>(2+) | VPA | Almeida and Anderson 1981a | No USA management FMP in preparation |
| Gulf of Maine American plaice | 4.3<br>(1963-1981) | 11.1<br>(1980) | 2.2<br>(1972) | 10.0<br>(1981) | kg/tow<br>(0+) | Autumn survey | Serchuk 1982 Unpublished data | No USA management FMP in preparation (ADF Plan) |
| Gulf of Maine Witch flounder | 2.3<br>(1963-1980) | 4.5<br>(1966) | 1.0<br>(1976) | 2.5<br>(1980) | kg/tow<br>(0+) | Autumn survey | Clark 1982 Unpublished data | No USA management FMP in preparation (ADF Plan) |
| Pollock | 4.8<br>(1968-1981) | 6.8<br>(1967) | 2.7<br>(1969) | 6.3<br>(1981) | kg/tow<br>(0+) | Spring survey | Clark et al. 1981a | No USA management FMP in preparation (ADF Plan) |
| Redfish | 23.5<br>(1963-1981) | 54.6<br>(1964) | 12.2<br>(1981) | 12.2<br>(1981) | kg/tow<br>(0+) | Autumn survey | Mayo 1980 | No USA management FMP in preparation (ADF Plan) |
| Georges Bank Haddock | 153<br>(1935-1960) | 427<br>(1965) | 14<br>(1973) | 67<br>(1982) | $10^{-3}$tons<br>(2+) | VPA | Clark et al. 1982a | Managed under FMP |
| Georges Bank Cod | 8.7<br>(1963-1981) | 21.5<br>(1978) | 4.9<br>(1969) | 17.5<br>(1981) | kg/tow<br>(0+) | Autumn survey | Serchuk et al. 1982a | Managed under FMP |
| Georges Bank Yellowtail flounder | 4.9<br>(1963-1981) | 10.6<br>(1964) | 1.2<br>(1976) | 2.3<br>(1981) | kg/tow<br>(0+) | Autumn survey | Clark et al. 1981b | Managed under FMP |
| Georges Bank Silver hake | 143<br>(1955-1981) | 595<br>(1964) | 26<br>(1978) | 32<br>(1981) | $10^{-3}$ tons<br>(2+) | VPA | Almeida and Anderson 1981a | Managed under preliminary Fishery Management Plan (PMP) |
| Georges Bank Red hake | 0.8<br>(1970-1982) | 2.4<br>(1971) | 0.1<br>(1982) | 0.1<br>(1982) | kg/tow<br>(0+) | Spring survey | Almeida and Anderson 1981b | Managed under PMP |
| So. New England Yellowtail flounder | 9.2<br>(1963-1981) | 20.1<br>(1972) | 0.7<br>(1975) | 3.8<br>(1981) | kg/tow<br>(0+) | Autumn survey | Clark et al. 1981b | Managed under FMP |
| So. New England-Mid-Atlantic Silver hake | 93<br>(1955-1981) | 375<br>(1965) | 57<br>(1958) | 61<br>(1981) | $10^{-3}$ tons<br>(2+) | VPA | Almeida and Anderson 1981a | Managed under PMP |
| So. New England-Mid-Atlantic Red hake | 94<br>(1963-1981) | 174<br>(1965) | 30<br>(1977) | 38<br>(1981) | $10^{-3}$tons<br>(2+) | VPA | Almeida and Anderson 1981b | Managed under PMP |
| So. New England-Mid-Atlantic Scup | 6.2<br>(1968-1981) | 12.4<br>(1979) | 1.1<br>(1969) | 3.2<br>(1981) | kg/tow<br>(0+) | Spring survey | Mayo 1982 | No USA management FMP planned |
| Summer flounder | 0.3<br>(1968-1980) | 1.0<br>(1976) | 0.05<br>(1970) | 0.4<br>(1980) | kg/tow<br>(0+) | Spring survey | Fogarty 1981 | No USA management FMP in preparation |

Table 3: Continued

| Stock | Biomass | | | Current value | Biomass units | Index | Primary data source | Current Fishery Management Status |
|---|---|---|---|---|---|---|---|---|
| | Median | Maximum | Minimum | | | | | |
| Bluefish | 0.7<br>(1967-1981) | 1.5<br>(1974) | 0.01<br>(1968) | 0.6<br>(1981) | kg/tow<br>(0+) | Autumn survey | Anderson 1980 | No USA management<br>FMP developed |
| Gulf of Maine Herring | 103<br>(1963-1981) | 175<br>(1968) | 34<br>(1973) | 83<br>(1981) | $10^{-3}$tons<br>(4+) | VPA | Fogarty & Anthony 1982 | Managed under FMP through mid-1982. |
| Georges Bank Herring | 342<br>(1961-1977) | 1143<br>(1967) | Near 0<br>(1981) | Near 0<br>(1981) | $10^{-3}$tons<br>(4+) | VPA | Anthony & Waring 1980 a | Managed under FMP through mid-1982. |
| Atlantic mackerel | 915<br>(1962-1981) | 2827<br>(1970) | 567<br>(1962) | 780<br>(1981) | $10^{-3}$tons<br>(1+) | VPA | Anderson 1981 | Managed under FMP |
| Butterfish | 5.5<br>(1968-1982) | 20.6<br>(1980) | 2.9<br>(1975) | 5.2<br>(1982) | kg/tow<br>(0+) | Autumn survey | Waring & Anderson 1981 | Managed under FMP |
| *Loligo* squid | 28.3<br>(1968-1981) | 51.4<br>(1976) | 14.1<br>(1971) | 24.3<br>(1981) | $10^{-3}$tons<br>(0+) | Autumn survey | Lange 1982 | Managed under FMP |
| *Illex* squid | 5.4<br>(1968-1981) | 68.6<br>(1981) | 0.4<br>(1969) | 68.6<br>(1981) | $10^{-3}$tons<br>(0+) | Autumn survey | Lange 1982 | Managed under FMP |
| Total Finfish and Squids Gulf of Maine-Cape Hatteras | 3416<br>(1965-1981) | 8012<br>(1968) | 1934<br>(1975) | 3358<br>(1981) | $10^{-3}$tons | VPAs and Surveys | Clark and Brown 1979 | No USA management as a unit. |
| Georges Bank Sea scallops | 1.2<br>(1975-1982) | 2.5<br>(1978) | 0.6<br>(1982) | 0.6<br>(1982) | kg/tow<br>(meat)<br>($\geq$70 mm) | Scallop survey | Serchuk et al. 1982c | Managed under FMP |
| Mid-Atlantic Sea scallops | 0.3<br>(1975-1982) | 0.7<br>(1978) | 0.18<br>(1981) | 0.2<br>(1982) | kg/tow<br>(meat)<br>($\geq$70 mm) | Scallop survey | Serchuk et al. 1982c | Managed under FMP |
| Mid-Atlantic Surf Clam | 2.5<br>(1965-1982) | 4.3<br>(1982) | 0.5<br>(1977) | 4.3<br>(1982) | kg/tow<br>(meat)<br>(0+) | Surf clam survey | Murawski & Serchuk 1981 | Managed under FMP |
| Offshore American Lobster | 0.8<br>(1963-1981) | 1.3<br>(1964) | 0.5<br>(1970) | 0.9<br>(1981) | kg/tow<br>(0+) | Autumn survey | Fogarty et al. 1982 | FMP prepared |
| Gulf of Maine Northern Shrimp | 5.8<br>(1972-1981) | 45.8<br>(1968) | 1.6<br>(1977) | 3.0<br>(1981) | kg/tow<br>(0+) | Maine summer survey | Clark 1982 | Managed by States under ASMFC |

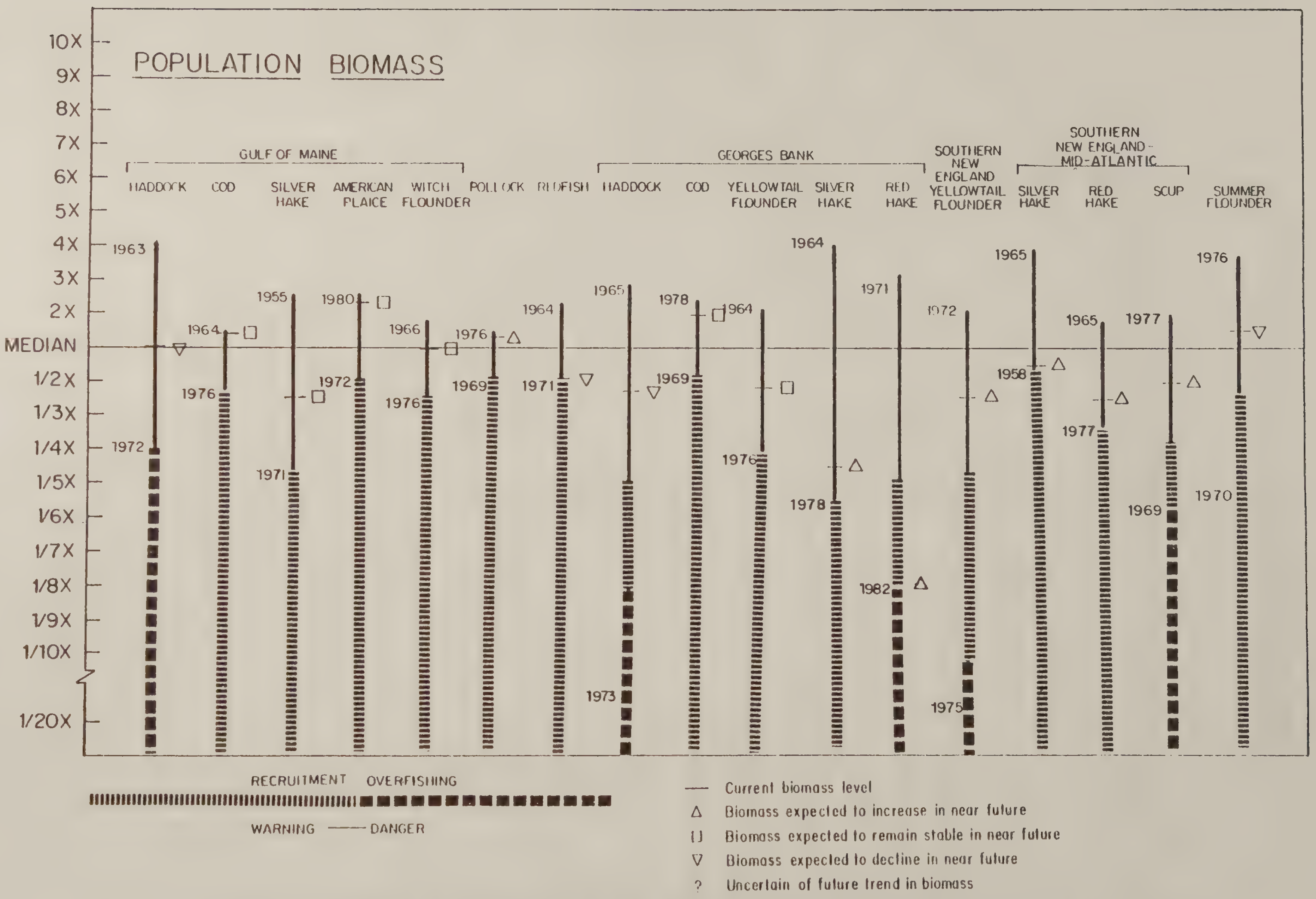

Fig. 20. Graphical summary of biomass patterns for major Northwest Atlantic finfish and shellfish resources (Serchuk *et al.*, 1982b).

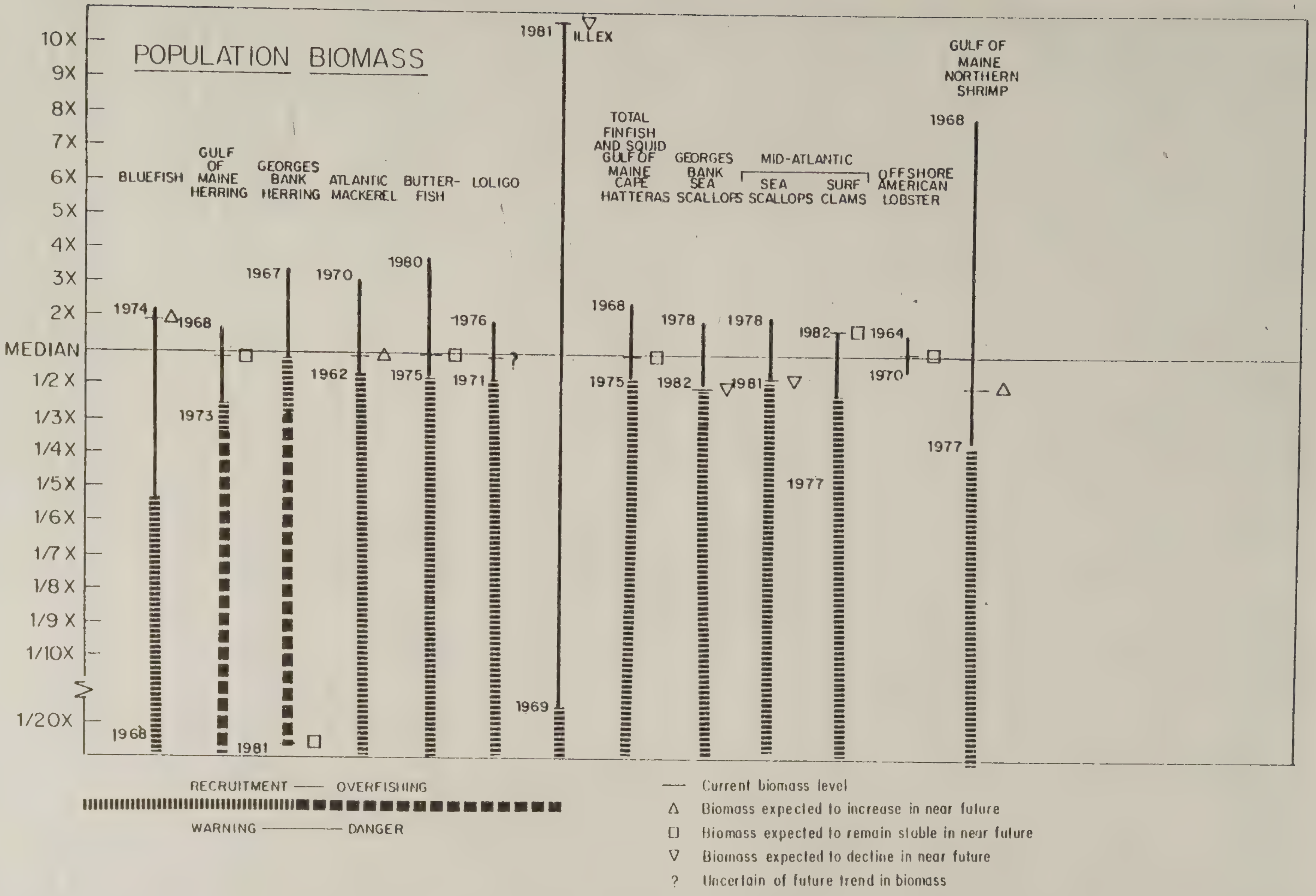

Fig. 20. Continued

2. The range of variability of biomass appears to be as large in demersal as it is in pelagic species. Relatively short-lived species such as squid, are probably more affected by environmental conditions causing large variations of biomass than longer-lived species like haddock or herring where biomass variations are also influenced by the number of age groups in the stock. When fishing activity reduces the number of age groups in the stock, as was the case for the Georges Bank haddock in the late 1960's and Georges Bank herring in the 1970's, large variations in biomass predominantly reflect recruitment success for single year classes, a situation normally observed in short-life species. It should be noted as we discussed in the species discussion that the expressed variations in *Illex* squid biomass is also a function of availability as this species often migrates out of the geographical range covered by Northeast Fisheries Center assessment surveys.

3. Currently more stocks appear to be increasing in biomass than decreasing. This is probably the result of the substantial reduction in foreign fishing effort in the past six years. Under more moderate fishing mortality circumstances, one might expect as many stocks decreasing in biomass as increasing. The difference among stocks in the time (years) at which maximum/minimum biomass levels were observed suggests such an expected pattern of biomass changes and the unlikelihood of all stocks being high at the same time.

4. For stocks harvested together in single fisheries, the relationship of current biomass and the expected direction of the biomass change with respect to the median and the warning and danger zones appear quite different among stocks. This suggests that simultaneous increases of biomasses of all components in the mixed fisheries is unlikely due to differential fishing mortalities generated by the current fishery on each component stock.

## IMPLICATIONS FOR RESEARCH

Galtsoff (1962) over 20 years ago wrote, "the most important scientific phase of this research is concerned with the causes of the great fluctuations in abundance of fisheries stocks. Life in the ocean...is in a state of unstable equilibrium in which the struggle for existence gives temporary predominance to one group which in turn may be replaced by another...the intricate picture of life in the open ocean cannot be illustrated by a single short-term observation of restricted area---Long and well planned observations are needed." This approach has been the basis for the research of the Northeast Fisheries Center for a quarter of a century and the results of this research form the basis for the paper presented here.

The guidelines of Galtsoff remain true today. It is vital to have a multipronged multidisciplinary research approach that addresses the total resource ecosystem if one is going to address the multispecies variability as it relates to the resource productivity. It is useful to examine the research program of the NEFC which has followed these guidelines and indicate what aspects have proven most valuable and what aspects require targeting at the present time in addition to maintaining a basic monitoring program.

This total program includes monitoring the catch, not only the total amount but also measures of quality whether by size, age, or both. It is also extremely valuable to have a regular measure of stock abundance of older juveniles and adults independent of the fishery. NEFC trawl surveys provide these indices. The precision of these indices certainly varies among species, but major trends can be determined for an extremely wide variety of species whether pelagic, semipelagic or demersal. It is important that survey coverage encompasses a fairly significant portion of the range of the resource to allow regular interpretation.

The NEFC ecosystem research program also monitored the basic physical oceanographic conditions, the icthyoplankton and the food habits of the fish taken. Zooplankton studies have indicated relative stability over long periods of time (Sherman et al., in press). Within the sampling network of the multispecies ichthyoplankton surveys, studies are conducted of the factors controlling growth and survival of target species, e.g., cod and haddock. Laboratory studies are now underway to confirm laboratory determinations of optimal prey densities with at-sea experiments on Georges Bank on the availability and abundance of suitable densities of zooplankton prey of cod and haddock. Plans are also being prepared to conduct predation experiments on eggs and larvae in large enclosures. Preliminary observations indicate that larval growth and survival is very high in predator-free, large, flow-through net mesh enclosures placed in a highly productive estuarine environment (Laurence et al., 1979).

Studies have also begun to monitor the incidence of disease. We are not yet at the stage where one can indicate their importance in the monitoring of natural mortality except, of course, in the classical incidences of massive die-offs from epizootics.

Pollution is an important concern in heavily populated areas of the northeastern United States. Recent studies have been conducted on cytogenic abnormalities in mackerel embryos in relation to concentrations of certain pollutants in the New York Bight region (Longwell, 1976, 1978; Longwell and Hughes, 1980). The egg stage may be most critical from the standpoint of the impact of man's pollutants which fish have not evolved to, as opposed to the variation in natural environmental factors. In cooperation with the U.S. Fish and Wildlife Service, studies were made by the NEFC (Buckley[4/]) of the viability of striped bass (*Morone saxatilis*) larvae from parents exposed to heavy metals and other toxins. Initial results indicate significant impact of the exposure to larvae hatched from the Hudson River parent stock.

Other pollution-related studies underway by NEFC in cooperation with the U.S. Environmental Protection Agency are focused on the impacts of exposures of larvae to urban sludge compounds identical to those now being disposed of on the continental shelf by the State of New York. One of the encouraging advances to study these effects at the NEFC is the use of RNA/DNA analysis for determining the growth potential of larvae collected routinely during the MARMAP surveys. High ratios indicate a "healthy" physiological condition for the larvae, while low values indicate that the growth potential of the larvae is impaired (Buckley, 1980, 1982).

Oceanographic studies have attempted to look at the possibility of major events such as advection of shelf water and associated shelf icthyoplankton. Warm core rings from the Gulf Stream have been observed entraining large volumes of shelf water across the shelf slope front into a nutrient-poor environment. It has been hypothesized that eggs and larvae of shelf species advected off the highly productive shelf in an entrainment feature would not survive in the prey-poor environment. Collections made in an entrainment experiment on the survival of ichthyoplankton in an entrainment feature revealed that no shelf species were in the entrainment, suggesting that warm core rings are not responsible for advective mortality of shelf larvae. Replicate experiments are planned to confirm these preliminary results (Laurence and Burns, 1982). A number of correlation studies have examined year classes on Georges Bank with environmental factors, such as offshore winds, slope frontal water and warm core rings and so far no relationship has been found that holds up over time. This may mean that significant larval mortality may occur at various times throughout the first year of life.

Although the survival of an individual larva is effected primarily by its own microenvironment, the extremely large differences between year class size (regularly 10 to 1 for many species) means that for environmental effects to be significant they must operate over the entire area that the larvae occupy. The accumulation of independent factors from microenvironments would average out over the area and thus not give the wide fluctuations with the regularity that they are observed. Further theoretical statistical studies could be of use in evaluating this hypothesis and to determine the relative sizes of areas for which it would be useful to evaluate environmental conditions if one is to examine year class survival.

The intensive efforts that have been made in the Northwest Atlantic to relate egg and larval work to predictions of recruits indicate that this procedure is not likely to be successful. These surveys are useful for other purposes such as independent estimates of spawning stock size in some situations and for indicating areas and times of spawning.

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[4/] Laurence J. Buckley, NEFC, Narragansett Laboratory, Narragansett, RI, personal communication.

The results to date would indicate that the next step in NEFC research will be to target on postlarval fish and to focus more resources on the actual recruitment processes. This understanding is most important for elucidating general principles that can be used for determining strategies of management. Logistical problems make monitoring unlikely except in very unusual situations for use in tactical management. This research effort will involve focusing on sampling at the postlarval and early juvenile stage and in evaluating the effects of predation. Here again this means extensive continuation of food habits studies of species most likely to prey on young fish. This does not mean that it is not necessary to continue at some level the background work of egg and larval surveys, oceanographic conditions, and even increased efforts on factors that affect the production of eggs by adult fishes such as changes in fecundity with stock size. It does, however, mean a concentration of NEFC resources on the postlarval period and the effects of fish predation thereon in the next period of years with reduced efforts in the other areas. An important aspect of monitoring mortality at this stage is that it should give strategic information concerning ranges of variability and the potential year class fluctuations under a variety of species compositions. Such efforts involve both field studies and modeling efforts. In long range research considerations, in order for further development of an ecosystem approach to the management of fishery resources, it will be necessary to overcome present deficiencies in:

(1) Identifying the linkages between primary, secondary, and fish production;

(2) Quantifying predator-prey dynamics, and

(3) Understanding the relationship between stock-size and recruitment.

## IMPLICATIONS FOR MANAGEMENT

Rarely in a fisheries management situation is the information available that would be required to provide very precise advice to managers. Precise advice would allow managers to weigh the risks involved in the decisions they are required to make and to have a high confidence in the risks being taken. Traditionally, fisheries scientists have often given relatively conservative advice based on their knowledge of other situations where fisheries have collapsed under increasing and intense fishing pressure. The decision-makers in industry and government, on the other hand, have observed situations where despite increases in fishing, productivity was maintained and thus have tended towards an optimistic view. Frequently management decisions have turned out to be a compromise between these two positions.

The experiences over the past 25 years in the southern area of the Northwest Atlantic add to the accumulative total of information which comprise the background of fisheries scientists. This accumulated information allows fishery scientists to be somewhat more explicit in their advice concerning the historically observed consequences of extremely heavy perturbations in fishing on highly variable resources. This leads to a greater refinement in the types of risk statements the fisheries managers can interpret and utilize in making their decisions.

In the Northwest Atlantic total fishing pressure has been demonstrated to be so large that resource productivity can be reduced on an overall basis. This occurred both because of the desire to harvest a large number of species and the use of non-selective fishing gear. The level of reduction of this resource from an unfished state was an estimated 70% (Clark and Brown, 1977).

Further implication for management comes from observing the recovery of this resource after fishing effort was drastically reduced. One of the areas that managers have to consider is the time-frame for recovery. For the fisheries off the northwest coast of the US there is approximately 10 years of history of intensive management, the last 5 being very minimal fishing for many of these stocks. In the period between 5 and 10 years after reaching bottom levels, the total biomass shows partial recovery. The recovery has been greater for the demersal fisheries than for the pelagic species. The latter should be tempered with the understanding that the very high peak observed in the mackerel stock in 1971 may occur only occasionally. Nevertheless, herring on Georges Bank are virtually non-existent and silver hake on Georges Bank are at a very low level despite a relatively long period of constraints.

The species composition of the demersal fish community resembles very much that which existed prior to heavy fishing, and one does not observe change in any major sense. Conversely, in the pelagic stocks major changes occurred with the silver hake component, the predator of largest biomass in the 1960's, being replaced primarily with dogfish and with bluefish to a lesser degree. Thus the total predator biomass remained more constant even though silver hake did not. In addition, the failure of herring to return and the explosion of sand lance makes the composition of the pelagic resources quite different than it was earlier. Therefore, managers should be warned that extremely heavy fishing not only can result in depression of the resources with relatively long time frames for recovery, but at least on a short-term basis, the recovery may be in resources that are somewhat different in composition than existed earlier.

In examining species individually, it can be seen that the greatest declines in herring have taken place on Georges Bank in contrast with the Gulf of Maine, in silver hake on Georges Bank in contrast to Southern New England, in the haddock on Georges Bank in contrast to the cod stock. It should be noticed in all of these contrasts that the stocks that have reached the very lowest levels have not recovered, or have recovered to a moderate degree, such as haddock. In these cases, spawning stock was down to a very low level, approximately only 10% or less of that observed at the peak periods. Those herring and silver hake stocks which did reach such low levels but were reduced to only approximately 20 to 25% of peak levels are now recovering. Cod was reduced only moderately from peak levels but recovered quickly. Mackerel abundance was stabilized at the abundance level observed in the early 1960's which proved to be about 20% of that observed at the peak levels. These inferences are quite crude, but nevertheless, the histories of such disastrous reductions serve as warning flags for fishery managers.

Finally, we should note the situation with the haddock recovery in which industry demands, when recovery was fueled by a single year class (1957), created the situation in which the spawning stock size was not rebuilt up to a robust multiage group state. Therefore, a vigorous fishery removed most of this abundant year class and the year class (1978) which followed from the first spawning of the 1975 year class, so rapidly that recovery, although large, was brief, and the stock is once again declining to the lower levels of abundance observed earlier. This situation was complicated for fisheries managers by the mixed nature of the fishery, particularly the relatively abundant populations of cod. Small quotas in place for haddock were caught quickly and the large populations of haddock made it impossible to pursue a fishery for cod and other groundfish without greatly exceeding haddock quotas designed to allow only very low fishing mortality rates so that haddock spawning stock biomass could be rebuilt. Fishery scientists are now in a position of pointing out to managers and industry officials an historic case where observing a recovery and taking immediate advantage of it initially may result in that recovery being very short in duration.

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*NORTH EAST ATLANTIC - ATLANTICO NORDORIENTAL*

# THE DECLINE IN HERRING AND MACKEREL AND THE ASSOCIATED INCREASE IN OTHER SPECIES IN THE NORTH SEA

by

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## Resumen

Han habido cambios marcados en la composición por especies en el Mar del Norte, asociados con una disminución de los desembarques de sardineta, anguila, platija y varias especies de gadidos. Hay también una evidencia de cambios en la abundancia de varias especies de invertebrados, y en particular de una extensa disminución de la biomasa total de copépodos en el período de 1948 a 1970.

En conclusión parece que:

a) La disminución de caballa estuvo asociada con el desarrollo de la pesquería Noruega con red de cerco.

b) La disminución de arenque pudo ser debida inicialmente a factores naturales, pero es probable que la pesquería también haya jugado un rol importante partícularmente en años recientes.

c) La distribución de varias especies de peces durante sus períodos de alimentación pelágica son tales que las sobreposiciones principales ocurren entre anguilas y caballa por un lado, y entre arenques y platijas, y arenque y sardineta por el otro lado.

d) La disminución de biomasa de caballa y el aumento de los desembarques de anguila son ambos comparativamente eventos recientes. La caballa disminuyó principalmente entre 1965 y 1970 y los desembarques de anguila aumentaron después de 1970. Parece que hubo un aumento de la dominancia de anguila, y que esto puede haber estado asociado con una reducción de la predación por parte de caballa.

e) La disminución de arenque y el total de copépodos y el aumento de platija son eventos de largo tiempo que comenzaron como a fines de los años 1940s sino antes. No es fácil ver como estos cambios pudieron todos ser debidos a la pesca inicialmente, aun cuando la pesca ha jugado probablemente un rol importante en reducir la biomasa de arenque a un nivel relativamente muy bajo hacia los años 1970s.

f) En el caso de sardineta y gadoidos es difícil decir hasta que punto el aumento de los desembarques fue debido a la disminución de arenque y caballa.

## INTRODUCTION

During the 1960s there was a decline in the landings of herring and mackerel, and an associated increase in the landings of various other species. The object of this paper is to examine the nature of these changes and the factors which might have caused them.

### Changes in the species composition of the landings

Table 1 shows the landings of selected species from the North Sea for the period 1960-1980. Over this period, herring and mackerel declined in importance, while sprat, sandeel, Norway pout, cod, haddock, whiting, saithe and plaice landings all increased.

### Species that declined

The principal species that declined in the North Sea were herring and mackerel. Herring, started to decline in the 1940s, due to a decline in the Downs Stock which is the most southerly of the three N. Sea herring stocks. This stock has remained at a very low level until very recently. In the 1950s there was a decline in the central area (the Dogger stock). Finally, the northerly stock (the Buchan stock) declined in the 1960s (Burd, 1978).

Regarding mackerel, there was a very considerable decline in stock size between 1965 and 1970, associated with the development of the Norwegian purse-seine fishery. Since then the stock has declined further due to poor recruitment.

### Species that increased

Species for which landings increased, were sprat, sandeel, Norway pout, cod, haddock, whiting and saithe and plaice. For all these species, landings increased to relatively high levels by the end of the 1960s, or at various times during the 1970s (Tables 1 and 2).

TABLE 2

Years in which landings attained maximum values

| Sprat | Sandeel | Norway Pout | Cod | Haddock | Whiting | Saithe | Plaice |
|---|---|---|---|---|---|---|---|
| 1975 | 1978 | 1974 | 1972 and 1980 | 1969 | 1969 and 1976 | 1971 and 1976 | 1970 and 1973 |

The largest increases were in the landings of sprat, sandeels, Norway pout and saithe. Sprat landings increased from less than 31,000 tonnes in 1962, to a maximum of 418,000 tonnes in 1975. Sandeel landings increased from about 100,000 tonnes at the beginning of 1960s to a maximum of 789,000 tonnes in 1978. Norway pout landings increased from 43,000 tonnes in 1974. Saithe landings increased from less than 50,000 tonnes at the beginning of 1960s to 253,000 tonnes in 1976. Lesser increases also occurred in cod, haddock and whiting during the 1960s. Cod and whiting landings increased by about a factor of 2 and haddock landings by a factor of 3-4. All eight species attained high levels of landings at various times between 1969 and 1976, and all, except cod, sandeels, and possibly plaice, showed a tendency for landings to decline during the second half of the 1970s.

### Magnitudes of the changes in stock size

Table 3 contains estimates of stock biomass for those species for which useful estimates can be made. For herring, total North Sea spawning stock biomass declined from just under 2 x $10^6$ tonnes at the beginning of the 1960s to 350 x $10^3$ tonnes at the end of the 1960s.

TABLE 1

N.Sea - Landings(1) of selected fish species (000's tons)

| Year Class | Herring(2) | Mackerel(3) | Sprat | Sandeel | Norway Pout | Cod(4) | Haddock(4) | Whiting(4) | Saithe(5) | Plaice |
|---|---|---|---|---|---|---|---|---|---|---|
| 1960 | 696 |  |  | 121 | 31 | - | 219 | 181 | 32 | 87 |
| 1 | 697 |  |  | 83 | 29 | - | 219 | 325 | 33 | 85 |
| 2 | 628 | 79 | 31 | 109 | 150 | - | 453 | 221 | 26 | 87 |
| 3 | 725 | 73 | 68 | 162 | 138 | 110 | 271 | 258 | 32 | 107 |
| 4 | 871 | 115 | 68 | 128 | 61 | 118 | 379 | 147 | 60 | 110 |
| 5 | 1169 | 208 | 72 | 131 | 43 | 178 | 298 | 185 | 78 | 96 |
| 6 | 896 | 530 | 102 | 143 | 53 | 218 | 346 | 240 | 96 | 100 |
| 7 | 696 | 930 | 67 | 189 | 183 | 247 | 246 | 234 | 79 | 109 |
| 8 | 718 | 822 | 61 | 194 | 452 | 279 | 302 | 237 | 104 | 111 |
| 9 | 547 | 736 | 60 | 113 | 114 | 196 | 929 | 324 | 114 | 121 |
| 1970 | 563 | 322 | 46 | 191 | 238 | 230 | 806 | 262 | 222 | 130 |
| 1 | 520 | 244 | 60 | 382 | 305 | 328 | 444 | 192 | 252 | 114 |
| 2 | 490 | 189 | 77 | 358 | 445 | 350 | 351 | 188 | 218 | 123 |
| 3 | 484 | 327 | 156 | 297 | 346 | 236 | 305 | 266 | 195 | 130 |
| 4 | 275 | 298 | 188 | 525 | 736 | 203 | 364 | 290 | 232 | 113 |
| 5 | 313 | 263 | 418 | 428 | 560 | 191 | 448 | 300 | 240 | 109 |
| 6 | 175 | 306 | 409 | 438 | 435 | 212 | 368 | 358 | 253 | 109 |
| 7 | 46 | 260 | 168 | 786 | 390 | 198 | 217 | 288 | 189 | 108 |
| 8 | 11 | 149 | 187 | 789 | 270 | 289 | 173 | 179 | 140 | 93 |
| 9 | 19 | 153 | 151 | 578 | 320 | 316 | 142 | 237 | 114 | 109 |
| 1980 | 11 | 88 | 107 | 729 | 670 | 421 | 219 | 225 | 123 | 102 |

(1) From ICES Working Group Reports and Anon, 1974
(2) Includes Division VIId
(3) Includes Division IIIa
(4) Includes discards and landings by industrial fishing (not available for cod prior to 1963)
(5) Excluding by catch from industrial fishing - includes Division IIIa

Table 3

The adult stock sizes of major species in the North Sea

| Species | Biomass of Stock 000's of tonnes | | | |
|---|---|---|---|---|
| | Early 60's (period) | Late 60's (period) | Age Groups | M(1) |
| Herring | 1840<br>(1959-61) | 350<br>(1968-70) | 2-8 | 0.1 |
| Mackerel | about 3000<br>(early 1960) | 800<br>(1968-70) | 2-7 | - |
| Cod(3) | 192<br>(1963) | 367<br>(1968-70) | 2-12 | 0.2 |
| Haddock(3) | 118<br>(1959-61) | 597<br>(1968-70) | 2-8 | 0.2 |
| Whiting(3) | 102<br>(1959-61) | 217<br>(1968-70) | 2-8 | 0.2 |
| Saithe | 193<br>(1960-62) | 917<br>(1971-73) | 2-14 | 0.2 |
| Plaice | 390<br>(1959-61) | 477<br>(1970-72) | 2-20 | 0.1-0.25(2) |

(1) Value of M assumed for determining stock size

(2) Values of M taken at 0.25 and 0.20 for 2 year old males and females and 0.15 and 0.10 for older males and females respectively

(3) Based on data in Anon, 1976

It is interesting to note that recently, there have been indications of a recovery of the Downs stock.

For mackerel, spawning stock biomass declined from about 3 x $10^6$ tonnes to about 800 x $10^3$ tonnes over the same period.

Haddock, whiting and cod stocks appeared to reach high levels at the end of the 1960s and beginning of the 1970s, and stock sizes have been compared for the periods 1959-61 and 1968-70. For these three species, estimates have been taken from Jones, 1982, based on data from an early report of the North Sea Roundfish Working Group (Anon 1976). More recent reports of this Working Group have reviewed these biomass estimates upwards to take account of fish discarded at sea. Due to uncertainties about rates of discarding prior to the late 1970s however, these more recent data are more valuable for estimating current levels of biomass, then for comparing changes in biomass in the long term. Based on the results in Table 3, cod and whiting stocks increased by about 100% and the haddock stock by about 400% during the 1960s.

Estimates for saithe and plaice have been taken from more recent reports of the ICES Saithe and Flatfish Working Groups. Saithe biomass reached a maximum early in the 1970's. Comparison of stock sizes for the periods 1959-61 and 1971-73 showed an increase of about 375% (Table 3). The plaice story differs somewhat from that of the gadoid species in that increases in landings and stock size first became evident as early as the 1950s. By the 1960s and early 1970s, stock size was levelling out and the increase between the periods 1959-61 and 1970-72 was only 22%.

## Variations in recruitment

For all species for which data is available, increases in stock size and/or landings have been associated with strong recruit year classes. Table 4 shows recruitment indices for those species for which data are available.

TABLE 4

N.Sea - Recruitment Indices for selected species

| Year Class | Herring (1) | Mackerel (1) | Sandeel (1) | Norway Pout | | Cod (3) | Haddock (3) | Whiting (3) | Saithe (1) | Plaice (1) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (2) | (3) | | | | | |
| 1960 | 13892 | | | 28 | | | | | | 405 |
| 1 | 6276 | | | 182 | | | | | | 350 |
| 2 | 7532 | | | 142 | | | Very good | Good | | 356 |
| 3 | 9397 | | | 7 | | | | | | 1136 |
| 4 | 5017 | | | 19 | | 16 | | 418 | | 330 |
| 5 | 4630 | | | 6 | | 20 | 12 | 600 | 156 | 321 |
| 6 | 6246 | | | - | | 28 | 62 | 501 | 422 | 294 |
| 7 | 6101 | | | 243 | | 5 | 5855 | 2019 | 442 | 254 |
| 8 | 3350 | 1353 | | - | | 6 | 81 | 19 | 474 | 334 |
| 9 | 7363 | 3482 | | 33 | 35 | 72 | 27 | 70 | 241 | 375 |
| 1970 | 5816 | 439 | | 112 | 1556 | 85 | 873 | 223 | 240 | 288 |
| 1 | 3789 | 592 | 37 | 329 | 3425 | 4 | 740 | 339 | 243 | 233 |
| 2 | 1810 | 328 | 58 | 17 | 4207 | 38 | 187 | 1159 | 281 | 553 |
| 3 | 4375 | 518 | 65 | 122 | 25626 | 15 | 1072 | 322 | 699 | 473 |
| 4 | 673 | 653 | 90 | 10 | 4242 | 96 | 1168 | 893 | 218 | 345 |
| 5 | 623 | 368 | 62 | - | 4600 | 9 | 177 | 679 | 161 | 329 |
| 6 | 857 | 171 | 116 | 132 | 4813 | 40 | 162 | 418 | 116 | 505 |
| 7 | 675 | 19 | 155 | 84 | 1913 | 14 | 385 | 513 | 92 | 509 |
| 8 | 1864 | 92 | 90 | - | 2690 | 10 | 480 | 457 | 155 | 684 |
| 9 | 1371 | 60 | 121 | - | 4081 | 26 | 896 | 692 | 202 | 1053 |
| 1980 | | | | 19 | 1375 | 13 | 268 | 227 | 200 | |

(1) Millions of fish at age 1 year from VPA
(2) Abundance indices from Scottish autumn surveys in north western North Sea
(3) Abundance indices from International Young Fish Surveys

For example, in the case of cod, haddock, whiting and saithe, the increases in stock sizes were all associated with the appearance of strong year classes. For cod there were strong year classes in 1969, 1970 and 1974. For haddock, the year class of 1962 and 1967 were the two strongest on record and those of 1973 and 1974 were also strong. For whiting there were strong year classes in 1962, 1967 and 1972. For saithe there were strong year classes in 1966, 1967, 1968 and 1973.

For plaice, the recruitment indices have remained at a consistently high level from 1963 to 1980.

Recruitment indices for Norway pout (Table 4) appear to be less reliable than those for the other species above. Available data however, suggests strong year classes in 1967, 1971 and 1973. There is only a short series of recruitment indices for sandeels, but this does provide evidence of strong year classes in 1976 and 1977, immediately prior to the very high landings in 1977 and 1978.

In summary, cod, haddock, whiting, saithe, plaice, sandeels and Norway pout all show evidence of increases in landings associated with strong year classes.

There are no recruitment indices for sprat over the period when landings first increased in the early 1970's and all that can be said for this species is that there is no reason to suppose that the increase in landings was not due to the same factors as were associated with the increases in other species.

Regarding the two species that showed decreases in stock size, both herring and mackerel exhibited relatively low levels of recruitment in the 1970s, at a time when the adult stock sizes were relatively very low.

## Geographical distributions of the principal species

Opportunities for species interaction should be greatest on those occasions when species occupy the same geographical area, at the same time, and when they are feeding on the same kind of food. Although some of the species concerned are pelagic, whereas others are demersal, all are pelagic feeders at some time or other in their lives. Herring, mackerel, sprat, sandeels and Norway pout are pelagic feeders throughout their lives, whereas plaice and gadoid species feed pelagically as 0-group fish during the summer of their first year of life. It is appropriate therefore to consider the geographical distributions of herring, mackerel, sprat, sandeels, Norway pout and 0-group gadoids during the summer months. This has been done, based on data in Anon (1978) and Walsh (1974), and a summary diagram showing the main centres of density of these groups is given in Figure 1.

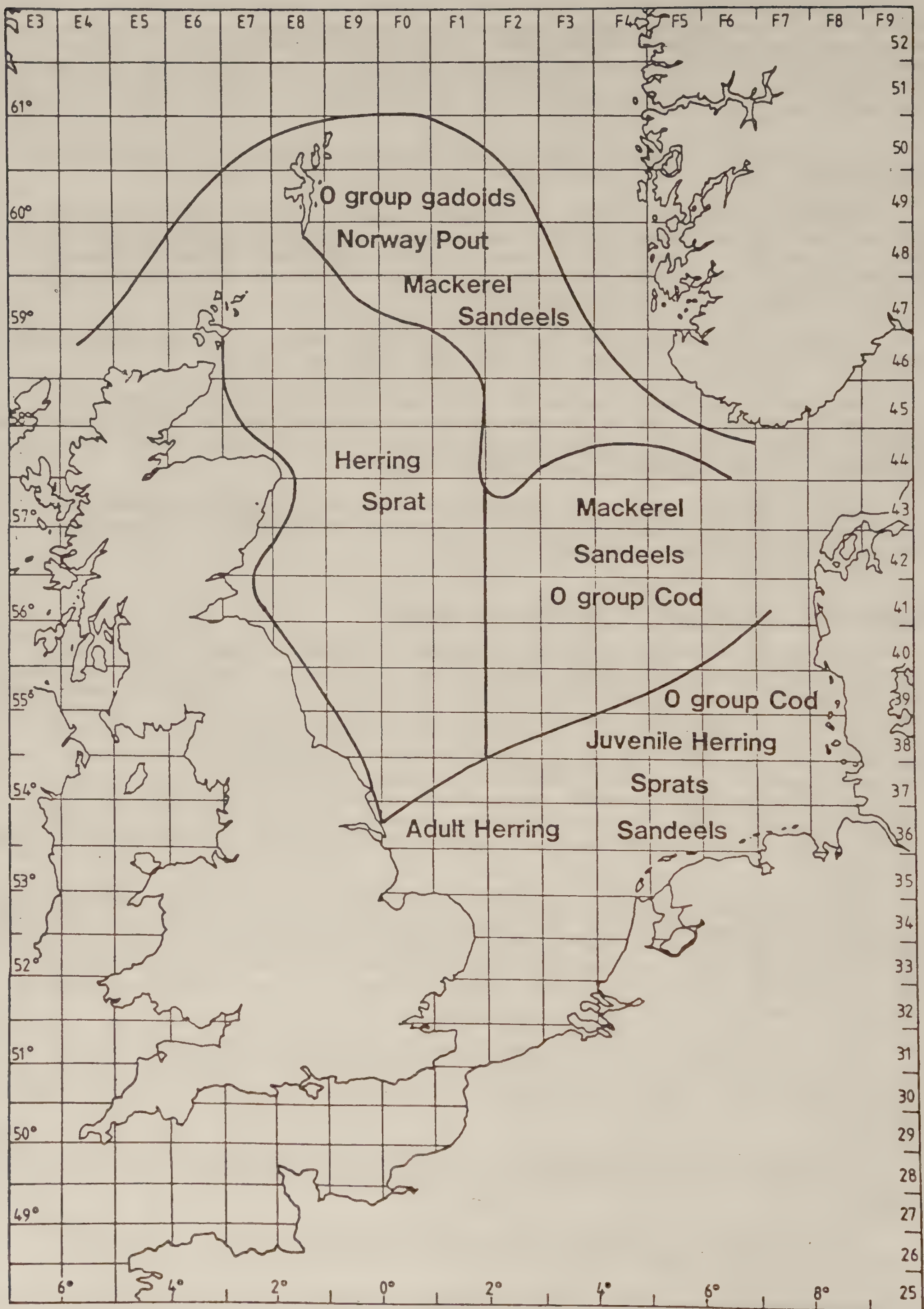
During the summer, the main centres of density of herring are in the southern North Sea, south of latitude 54° north, and between latitudes 54° and 60° north, west of 2° east longitude. Mackerel on the other hand are found mainly in the northern North Sea, and in the central North Sea to the east of 2° east longitude. Although there is an overlap in the distributions of these two species, there is a clear distinction between their main centres of density.

Sprat and sandeels also show a separation of their main centres of density. In general, it appears that sprat distribution primarily overlaps with that of herring, whereas sandeel distribution overlaps more extensively with that of mackerel and juvenile herring.

Norway pout are found principally in the northern North Sea, north of latitude 58°30' north, and overlap with the northerly limits of the herring and mackerel summer feeding areas.

0-group haddock are found principally north of latitude 59° north, but extended a little further to the south in the eastern part of the North Sea.

0-group whiting are found in the northern Nort Sea and in the south-eastern North Sea and also inshore along the east coast of the UK.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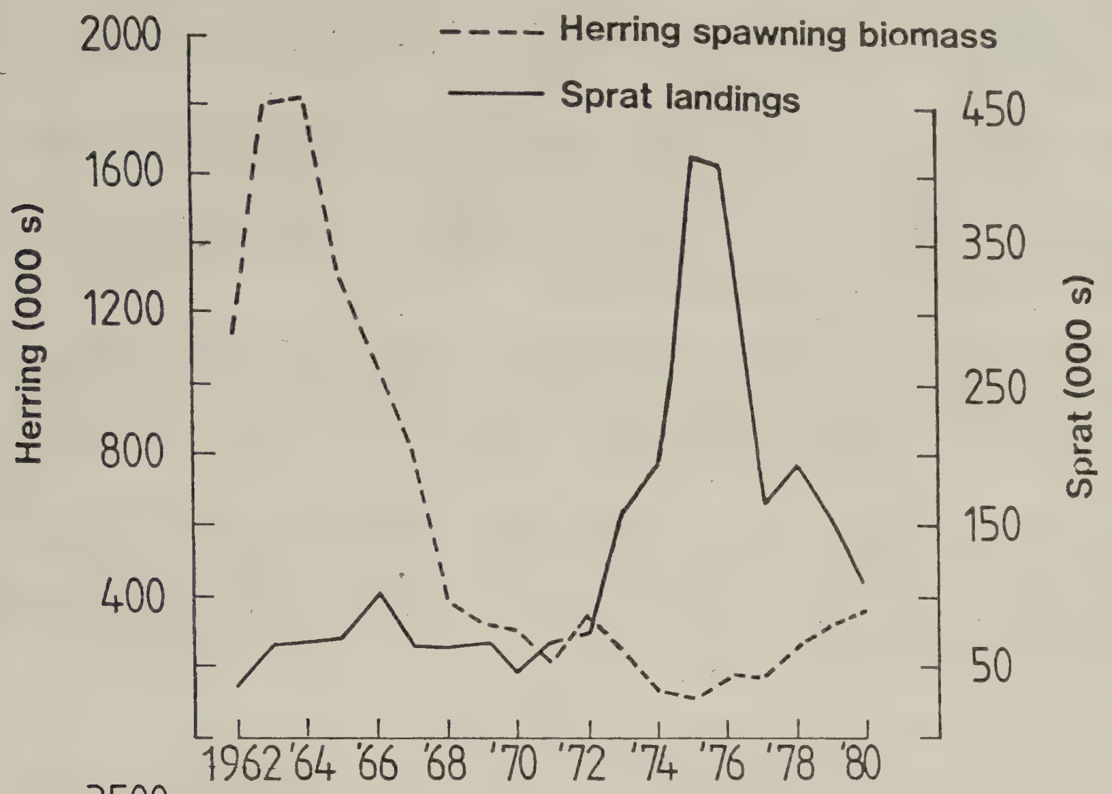
Norway Pout
Mackerel
Sandeels
Herring
Sprat
Mackerel
Sandeels
O group Cod
O group Cod
Juvenile Herring
Sprats
Sandeels
Adult Herring

Figure 1 Locations of centres of density of principal pelagic feeding stages during the summer.

Figure 2. Annual variations in herring spawning biomass and sprat landings in the North Sea.



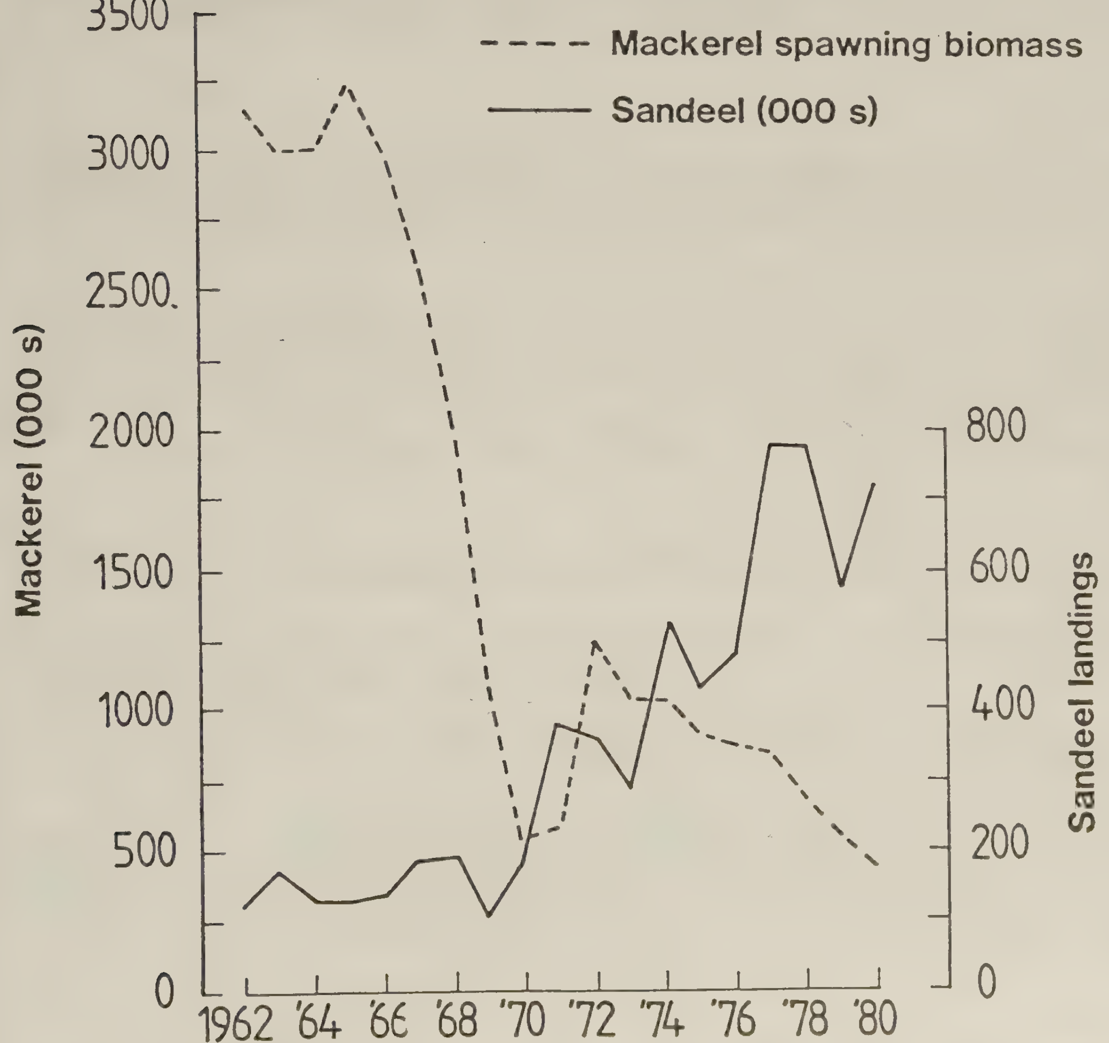


Figure 3. Annual variations in mackerel spawning biomass and sandeel landing in the North Sea.

## Opportunities for species interactions

Species that overlap, and hence that have an opportunity for interaction, can be grouped as follows:

(a) Herring and sprat. It can be noted that maximum sprat catches in the mid 1970s coincided with the period of minimum herring stock size (Fig. 2)

(b) Mackerel and sandeel. Here, it can be noted that there was a significant increase in sandeel landings the whole of the 1970s, at a time when the mackerel stock size was at a very low level (Fig. 3).

(c) Plaice and herring. The main concentrations of plaice, in the southern and south-eastern North Sea overlap with a major herring nursery area and with the region occupied by the Downs stock of herring. It can be noted that the increase in plaice landings became particularly noticeable during the 1950s at a time when the Downs herring had dropped to a relatively low level.

(d) Gadoids, herring and mackerel. The young stages of cod overlap principally with mackerel, those of whiting and Norway pout principally with herring, and those of haddock with both herring and mackerel. Out of the four gadoid species, the largest increase was in haddock, ie with a species that might have benefitted from decreases both in herring and in mackerel. Saithe also showed a large increase, but detailed information about its distribution is not available.

## CAUSES OF THE CHANGES IN SPECIES COMPOSITION

There are two principal factors that could have accounted for the changes in species composition. One is exploitation and the other is natural variation.

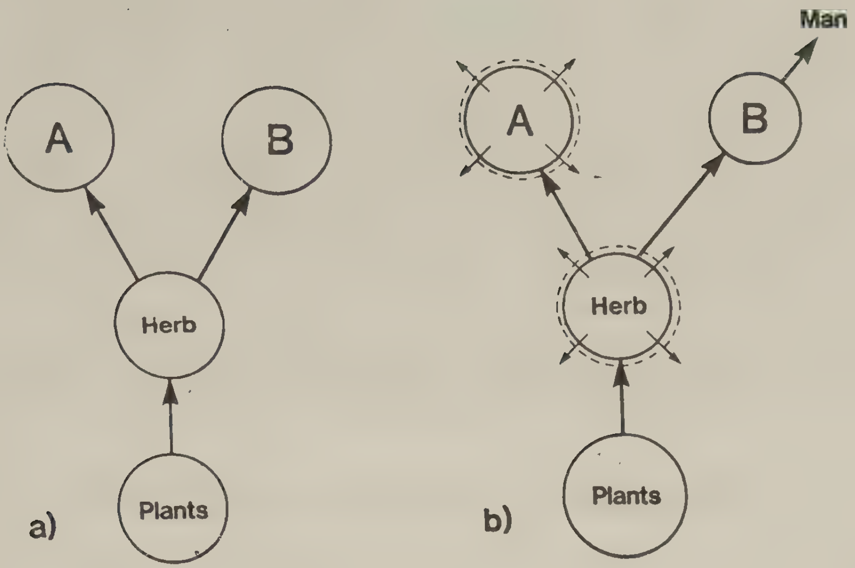
### Exploitation

Exploitation has almost certainly played a large part in the decline of the herring and mackerel stocks. In the case of mackerel, in particular, the considerable decline in stock size between 1965 and 1970 was clearly associated with the development of the Norwegian purse-seine fisheries.

In the case of herring, the decline has taken place over a relatively long period, starting with a decline in the Downs stock in the 1940s followed eventually by a decline in the Buchan stock in the 1960s. For both species, recruitment was exceptionally low during the 1960s and this was the direct cause of the very low stock levels attained by the end of the 1970s. What is not clear is whether this poor recruitment was due to natural causes, or whether it was due to the low levels of spawning stock brought about by exploitation.

In the case of sprat, sandeel and Norway pout, landings could have been influenced by the diversion of effort from the industrial fisheries for juvenile herring and whiting.

Regarding the species that increased in stock size, consideration of the possible effects of exploitation depends on the trophic interactions between those species/stocks that happen to overlap in space and time. Figure 4(a) and (b), for examples, shows the simplest kind of situation in which the herbivores are grazed by two groups of species, A and B. Here, exploitation is assumed to decrease the biomass of group B, leading to a reduction in grazing pressure on the herbivores. This, in turn, could make more food available for other species and might be expected to lead to an increase rather than decrease and this, therefore might be representative of trophic interactions in the north western North Sea, where copepod biomass does not appear to have declined. This has been an important summer feeding area for herring, and the decline in this species might have made more food available for other pelagic feeders in the same area ie principally for sprats and for the young, pelagic feeding stages of gadoids.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b)

Figure 4 Some Trophic Interactions - I

(a) without exploitation - Two groups, "A" and "B" assumed to be grazing on herbivores;

(b) suggests that with exploitation of group "B", more food should be available for group "A". Likely outcome should be increase in biomass of both herbivores and of group "A".

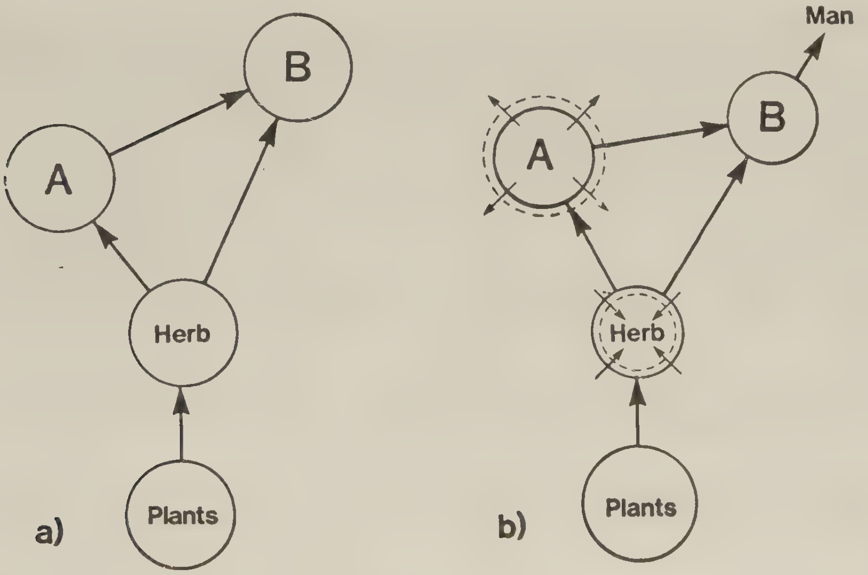
Man
B
A
Herb
Plants
a)
A
B
Herb
Plants
b)

Figure 5 Some Trophic Interactions - II

(a) without exploitation - Two groups, "A" and "B" assumed to be grazing on herbivores. In addition, group "B" species prey on group "A";

(b) suggests that with exploitation of group "B". Group "A" should benefit from reduced predation. Posible outcome could be increase in group "A", but decrease in biomass of herbivores.

In the central and southern North Sea, however, there has been decline in total copepods and to account for this, something along the lines of the scheme in Figures 5(a) and (b) would seem to be more appropriate. Here it is assumed that the group B species prey on the group A species as well as on the herbivores. In this situation, it is possible for a reduction in the biomass of group B to lead not only to an increase in group A but also to a decrease in the herbivore biomass. This model is representative of a situation in which the principal exploited species is an important predator on other primary carnivores. It might be applicable therefore to mackerel (group B) and sandeels (group A) or to mackerel and euphausids. (In this connection one can note that there was an increase in euphausids in the 1970s in the eastern part of the central North Sea, at a time when mackerel biomass was low (Lindley 1979) as well as the increase in sandeels noted in connection with Fig. 3).

An over-exploitation of herring and mackerel might therefore have contributed to increases in sandeels, sprats and gadoids. All of these could have benefitted from an increased availability of food.

## The Contribution of natural processes to the change in species composition

The principal difficulty with exploitation as the primary causal factor for all of the changes in the North Sea is that it does not explain the time sequence of events. In particular, the decline in total copepod biomass appeared to start in the 1950s, whereas the decline in mackerel biomass, which might have caused it, did not occur until after the mid 1960s. The post-war decline in total copepods is paralleled much more closely in fact by the decline of herring. According to Glover et al. (1972) the decline in copepods was particularly marked in the case of *Pseudocalanus* and, according to Cushing (1980), this is taken in preference to *Calanus* by larval and post larval herring. This suggests therefore that the decline in herring was more likely to have been due to the decline in copepods, rather than viceversa.

The possibility of natural variability cannot be ruled out, and there is considerable evidence to show that there have been long term changes in many components of the ecosystem. For example, continuous plankton records, reported in various papers from the IMER, Plymouth laboratory, provide considerable evidence of long term changes in the zooplankton and phytoplankton of the North Sea. According to Glover et al. (1972), the total number of copepods and the zooplankton biomass in the North Sea have declined over the period 1948-69. Also the duration of the zooplankton season has fluctuated considerably, and has become progressively shorter over the period 1952-64. Regarding particular species, Colebrook (1978) concludes that *Pseudocalanus* declined from 1948 to about 1970 in all parts of the North Sea except for the northwestern North Sea, where it fluctuated about a constant level. To the west of the British Isles also it tended to decline.

Between 1970 and 1972, *Calanus finmarchicus* continued to decline in abundance, in contrast to *Calanus helgolandicus* in the southern North Sea, which did not show any systematic change in abundance (Colebrook et al., 1978).

From 1972 to 1977 in the eastern North Sea, euphausids increased in abundance in continuous plankton records (Lindley, 1979). The increase affected all five species, which normally occur in the area, but was not paralleled in other areas of the North Sea.

There have also been changes in the abundance of some fish larvae in the plankton. For example, over the period 1948-72 there has been a decline in the abundance of whiting, Norway pout, dabs and plaice larvae. The downward trend of whiting larvae started in 1964 whereas that for plaice has been general over the whole 25 year period (Coombs 1975). For whiting and sandeels there has been a shortening of the season during which the larvae have been caught and a delay in the time of the seasonal maximum abundance (Coombs 1975). According to Coombs and Mitchell (1981) there was a southerly shift in the distribution of mackerel larve in the North Sea over the period 1948-1977. Over a similar period, the abundance of larvae increased to reach high numbers by the late 1950s and subsequently declined after the mid 1960s.

According to Robinson & Jonas (1981), zooplankton abundance was still below average in most areas of the North Sea in 1980. In particular, numbers of *Pseudocalanus elongatus, Paracalanus ssp., Temora longicornis, Evadne nordmani* and pelagic molluscs were well below the long-term mean.

There is also evidence, from the same source, of changes in the phytoplankton. Reid (1977), for example, has concluded that in most areas of the northeast Atlantic Ocean, diatoms have declined in abundance in the last decade, while at the same time there has been an increase in phytoplankton colour. This refers to an unidentified green colouration of phytoplankton silks that may be due to the presence of organisms such as microflagellates, which may partially disintegrate in formalin leaving their chloroplasts in the silks. These would not be identifiable in the continuous plankton recorder samples. In particular, Reid (1975), referring to phytoplankton in the western part of the central North Sea, notes that before 1965, phytoplankton colour showed distinct spring and autumn blooms. After that date the productive season became longer, the distinction between the two blooms became less marked, and the autumn bloom declined in intensity.

The diatoms decreased markedly after 1965 and this was associated with a drastic decline in the autumn bloom. Winter and summer diatoms almost disappeared and there was also a decline in the spring bloom.

The time of the spring bloom has also changed. Glover et al. (1972) state that for the period 1948-69, the spring bloom of phytoplankton has occurred progressively later.

Regarding particular species of phytoplankton, Colebrook et al. (1978) examined fluctuations in the abundance of seven species of *Ceratium* that occur regularly in samples from the North Sea. All but one species showed an advance in seasonal timing in the south and eastern parts of the North Sea. None of the species showed any consistent change in seasonal timing in the northwestern part of the North Sea.

Some long term trends have also been noted in adult fish characteristics. According to Jones & Hislop (1978) for example, the mean lengths of two and three year old haddock in the North Sea, increased from the mid 1920s to reach relatively high levels by about 1960-1962. Jones (in press) shows that this increased growth rate appeared to be associated with the period when haddock first become demersal and prior to the attainment of a length of about 28 cm. An implication is that feeding conditions for juvenile haddock at the first demersal feeding stages, improved progressively for nearly 40 years, but that this was not associated with unusually strong recruitment, until the very good year classes of 1962 and 1967 appeared.

There is abundant evidence therefore to show that variability has occurred at various trophic levels, and often over considerable time periods.

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*NORTH EAST ATLANTIC - ATLANTICO NORDORIENTAL*

# RECENT HISTORY OF ATLANTO-SCANDIAN HERRING STOCKS

by

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## Resumen

El término "Arenque Atlanto-Escandinavo" (*Clupea harengus L.*) cubre tres stocks: "los desovantes de primavera de Noruega", "los desovantes de Primavera de Islandia" y los desovantes de verano de Islandia". Los desovantes de primavera de Noruega constituyen el stock más grande. El presente trabajo por lo tanto se concentra en este stock, pero también se refiere a los stocks de Islandia en un intento de resumir los cambios que siguieron la interacción entre la biología y la pesquería durante los últimos treinta años.

En general los tres stocks de arenque Atlanto-Escandinavo han tenido historias pararelas desde 1950 hasta 1980. La primera década fue caracterizada por stocks estables o en aumento. La biomasa de los stocks desovantes de la población que desova en primavera en Noruega fue en promedio de 8.5 millones de toneladas, mientras que la biomasa de los desovantes de invierno y de verano de Islandia era de alrededor de 500 000 y 135 000 toneladas, respectivamente. Estos tres stocks en total rindieron capturas anuales de 1 millón de toneladas aproximadamente. Durante la década siguiente todos los stocks declinaron rápidamente. Las capturas altas fueron mantenidas en los primeros años por el incremento en el ritmo de pesca, pero a inicios de los años 1970s los stocks y las capturas habían alcanzado su nivel más bajo. En esta época se introdujeron vedas de pesca y sistemas estrictos de cuotas de captura en un intento para lograr la recuperación de los stocks.

En la última década se ha observado una recuperación de dos de estos stocks, pero el ritmo de incremento ha sido diferente. En el momento, la biomasa del stock desovante de primavera de Noruega llega solamente a un 5% del promedio que ese stock tenía en los años 1950s, mientras que los desovantes de verano de Islandia han alcanzado los niveles altos observados entre 1958-1962. Los desovantes de Islandia de primavera, por otro lado no han mostrado signo de recuperación.

Las estadísticas de captura y registros de la pesquería de arenque Atlanto-Escandinavo a partir de los años 1800s indican que previamente hubieron amplias fluctuaciones de los stocks. Esto puede sugerir que la reducción de los stocks en los años 1960s fue inducida por factores bióticos. Sin embargo, se ha demostrado claramente que la rápida reducción de los stocks fue causada por una pesquería intensa, la que directa o indirectamente ha resultado en una reducción de reclutamiento y de aquí el total colapso de los stocks.

Este impacto de la pesquería fue el resultado de las grandes mejoras tecnológicas en la flota de los barcos pesqueros con redes de cerco a fines de los años 1950s y 1960s. Algunas innovaciones como por ejemplo los equipos acústicos para detección de peces, redes más grandes de fibra sintética y absorbentes para el pescado, combinadas con un cambio del método de pesca con dos pequeños botes hacia el uso de poleas hidraúlicas y la técnica de pesca con garetas hicieron que la flota fuera extremadamente eficiente inclusive en mar abierto.

A inicios de los años 1960s eran alrededor de 700 los barcos con redes de cerco que pescaban casi exclusivamente arenque Atlanto-Escandinavo. Hacia el final de la década la flota consistía de alrededor de 450 barcos con redes de gareta totalmente modernizados los cuales tuvieron que transferirse sucesivamente de la pesca arenque Altanto-Escandinavo, que ya casi no existía, hacia la pesca del arenque del Mar del Norte, la caballa y el capelin.

Durante los años 1970s la mortalidad por pesca de los adultos en todos los stocks aumentó desde un nivel de 0.15 hasta 1.0 aproximadamente. El incremento casi exponencial de la mortalidad por pesca fue el resultado del incremento de la capturabilidad asociado con la reducción del tamaño de los stocks, un fenómeno típico de pesquerías dirigidas hacía peces que forman cardúmenes.

Algunas características biológicas de los stocks tales como la distribución, migración, desove y crecimiento también cambiaron, en conexión con los cambios de la abundancia. En los años 1950s los individuos adultos del stock desovante de primavera de Noruega se alimentaban entre Islandia y Jan Mayen, pasaban el invierno al este de Islandia y migraban hacia el este hacia las extensas áreas de desove a lo largo de la costa oeste de Noruega. A medida que el stock adulto se redujo en los años 1960s el área de distribución se desplazó hacia el norte con nuevas áreas de alimentación y de invernación, y áreas de desove más reducidas hacia el norte. A inicios de los años 1970s no se observó desove, y en los últimos años los desovantes de primavera de Noruega se dividieron en dos componentes que ocurrían solo a lo largo de la costa con ninguna migración oceánica.

También se han observado cambios en el patrón de migración de los desovantes de verano de Islandia, particularmente en el tiempo en que ocurre la migración entre las áreas de desove al sur y sudeste de las costas de Islandia y las áreas de alimentación más al norte. Antes, los desovantes de primavera de Islandia ocurrían en las mismas áreas que el otro stock de Islandia, pero tenían una época de alimentación. En años recientes este stock ha sido mínimo, y solamente se le ha registrado como parte de una mezcla insignificante en las capturas de los desovantes de verano de Islandia.

Bajo la situación actual de los stocks, las autoridades responsables de ordenación de la pesca no tienen otra opción que tratar de balancear el interés en un rápido incremento de los stocks y las demandas de abrir la pesquería por razones socioeconómicas.

La presente revisión se ha basado mayormente en los trabajos de Dragesund, Hamre y Ulltang (1980), Jakobsen (1980 a,b), Bakken y Dragesund (1971) y los informes de grupos de trabajo de (ICES) sobre arenque Atlanto-Escandinavo.

## INTRODUCTION

The present review aims at describing changes in the stocks of Atlanto-Scandian herring (*Clupea harengus* L.) during the last thirty years and attempts to illustrate the interrelationship between stock dynamics and fisheries development.

Atlanto-Scandian herring must be ranked among the most important fish resources of the Northeast Atlantic with peak landings of more than 1.5 million tons in the mid 1950's. Today landings amount to merely 60,000 tons, and the herring fisheries are of minor importance. The remarkable decline in yield reflects the changes in the stocks, and the present situation can be considered transitional. The Atlanto-Scandian herring, therefore, remain important due to the potential for the future.

The term "Atlanto-Scandian herring" is now generally accepted to cover three stocks:

"Norwegian spring spawners"
"Icelandic spring spawners" and
"Icelandic summer spawners".

Since the Norwegian spring spawners constitute by far the largest stock, the term is frequently applied to that stock alone.

The present outline concentrates on the stock of Norwegian spring spawners, but refers also to the two Icelandic stocks as the recent history of all the stocks shows a series of similar characteristic events. The fluctuations in abundance and distribution of the stocks are well documented by a number of studies, primarily by Norwegian and Icelandic fisheries scientists organized in part as joint investigations. In later years assessments of the stocks are carried out under the auspices of the International Council for the Exploration of the Sea (ICES).

The review presented here is based mainly on papers by Dragesund, Hamre and Ulltang (1980), Jakobsson (1980a,b), Bakken and Dragesund (1971) and reports of the Atlanto-Scandian Herring Working Group published through annual reports by the ICES Advisory Committee on Fishery Management (Anon. 1982).

## GENERAL BIOLOGY

During the later decades the distribution and migrations of the Atlanto-Scandian herring have changed. The general features will, however, best be described by the situation observed prior to 1960 when the stocks were at a relatively high level. Fig. 1 gives a schematic illustration of the areas of spawning, feeding and overwintering with indications of migration.

### Norwegian Spring Spawners

Spawning takes place in February - March along the coast of Western Norway. After spawning the herring migrate westwards into the Norwegian Sea. During summer they feed heavily on zooplankton in the area northeast of Iceland along the front between cold and warm water masses. In autumn the herring concentrate in cold water east of Iceland and by December start on a spawning migration towards the Norwegian coast.

Herring larvae are transported by the current northwards along the Norwegian coast. Juveniles are found mainly in the fjords while adolescent herring occur both in the fjords of Northern Norway and in the western part of the Barents Sea and the northeastern Norwegian Sea. Maturity is normally reached at age 6-7 by a length of about 33 cm. Maximum age and length are 18-20 years and about 33 cm.

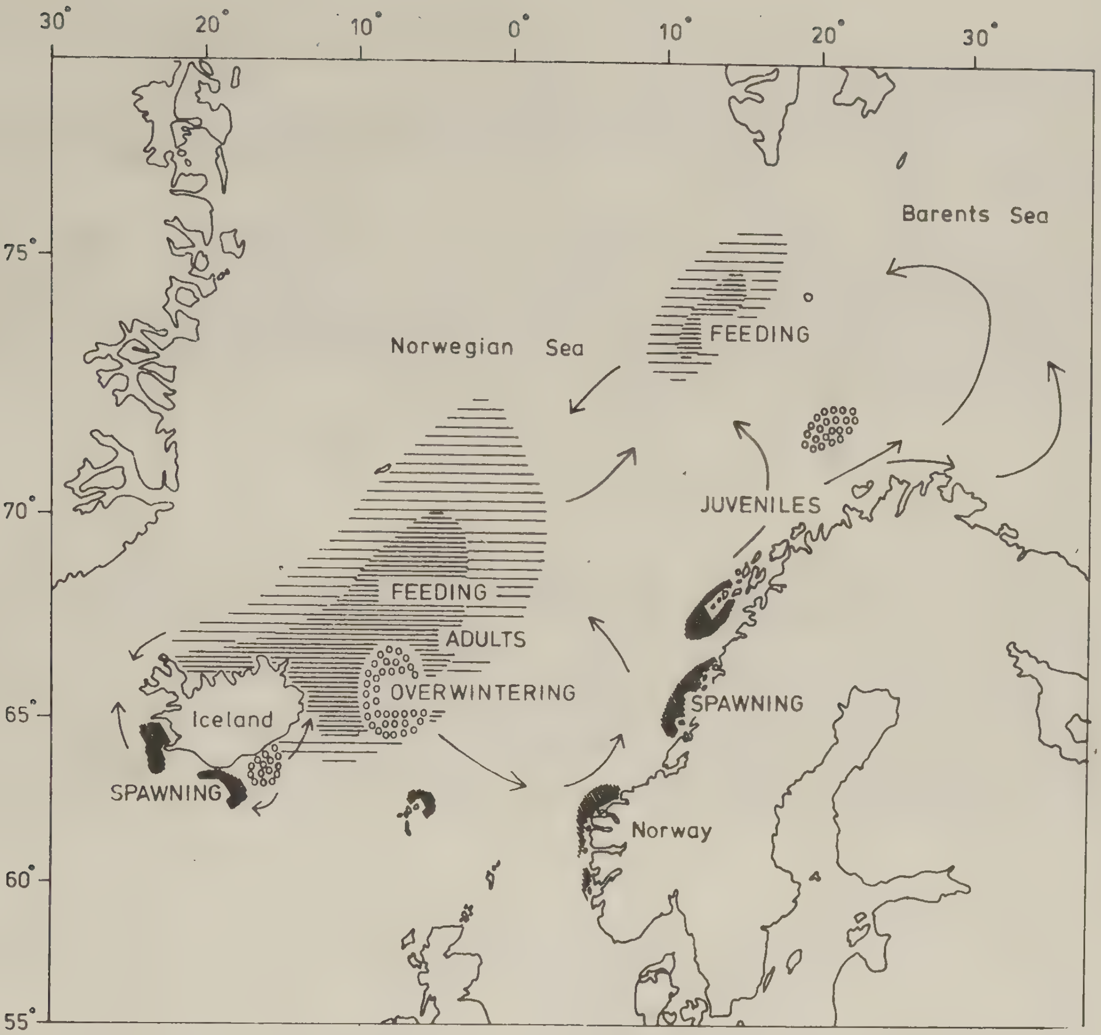

Fig. 1. Generalized illustration of the distribution and migrations of Atlanto-Scandian herring during a period of high stock level. (Modified from Anon. 1970 and Anon. 1974).

## Icelandic Spring Spawners

Herring of this stock spawn in March - April at various localities off the south coast of Iceland. The spent herring feed off the south coast and migrate by June northwards on either side of Iceland continuing feeding off the northeast and northwest coast, usually mixing with Norwegian spring spawners feeding in the same area. In late autumn the adult population starts to migrate west and south around West-Iceland to spawn (Jakobsson 1980a).

Herring larvae are carried with currents clockwise along the coast, and the main nursery grounds are in fjords and coastal areas of Northwest- and North-Iceland. At about 2 years of age they mix with the adult population. Maturation normally takes place at the age of 4.

## Icelandic Summer Spawners

Spawning takes place in July - August in the same general area as that of the Icelandic spring spawning herring off southern Iceland, but extends somewhat further west. During autumn the spent herring migrate northwards to Northeast- and Northwest-Iceland. At this time the distribution area overlap that of the two spring spawning stocks, although the summer spawners are generally found further south. In early winter the summer spawners migrate west of Iceland and remain during winter off the south coast near the spawning grounds.

As for the spring spawners, the larvae are transported westwards and north to the nursery grounds along the northwestern and northern coast. The summer spawners mature at 3-5 years of age.

The general biology of the three Atlanto-Scandian herring stocks are rather similar. The main difference is related to the dimensions of the distribution area and migrations. At high stock levels the Norwegian spring spawners utilize a major part of the Norwegian Sea for feeding while the Icelandic stocks are confined to the shelf area around Iceland. In general, the distribution area of each stock of Atlanto-Scandian herring corresponds to the relative size of the three stocks.

## STOCK SIZE AND CATCH

During the last 30 years the yield and stock size of the three Atlanto-Scandian herring stocks have changed dramatically. Although differences exist among the stocks the histories include a system of parallel events. In the following this is described by an examination of year to year changes in landings, in stock size and in exploitation. For all stocks reliable catch statistics and stock assessments are available, and this makes it possible to describe the development in quantitative terms. It is, however, more difficult to explain the causes of the observed changes. Still, it seems clear that the fisheries have played a major role. For this reason a later section attempts to quantify the changes in the fleet which exploited the stocks, particularly during the period of stock decline.

### Norwegian Spring Spawners

Fig. 2A shows the catches of Norwegian spring spawning herring during the period 1950-1980.

In the early 1950's about 70 per cent of the annual catch was taken by Norway along the coast during the spawning period. These catches declined sharply in the late 1950's from about 1 million tons to 400,000 tons by 1960. During the 1950's catches taken off shore by drift nets by the Soviet Union gradually increased, while catches of immature herring fluctuated around 200,000 tons annually.

In the first half of the 1960's the total catch again increased. This was in part due to rich year-classes of 1959 and 1960 (Dragesund, Hamre and Ulltang 1980), but was also a result of the extensive fishery on the open ocean, particularly in the northern part of the Norwegian Sea by purse seiners of Norway and Iceland. In 1966 and 1967 record catches of about 2.0 and 1.7 million tons were landed. This was followed by an immediate drop to only 70,000 tons in 1969.

During the 1970's catches have been governed by various fishing restrictions and less than 10,000 tons have been taken annually.

Fig. 2B shows the stock changes during the same period with an inserted graph illustrating the development of the fishing mortality rate 1955-1968. The data are taken from the comprehensive study by Dragesund, Hamre and Ulltang (1980) updated by stock estimates provided by Hamre for the ICES Advisory Committee on Fishery Management (Anon. 1982).

In the first half of the 1950's the spawning stock was at a level of about 8 million tons. The 1950 year class was strong and contributed to an increase in the spawning stock in the mid 1950's. In 1957 the stock was estimated at 10 million tons. From then on the stock declined until 1963. The decline was caused by reduced recruitment and the fishing mortality on the adults remained at about 0.15. Recruitment improved and the stock increased to 3.7 million tons in 1965. Catches, however, went up rapidly at the same time (Fig. 2A), and the fishing mortality increased steadily, also on the younger age groups.

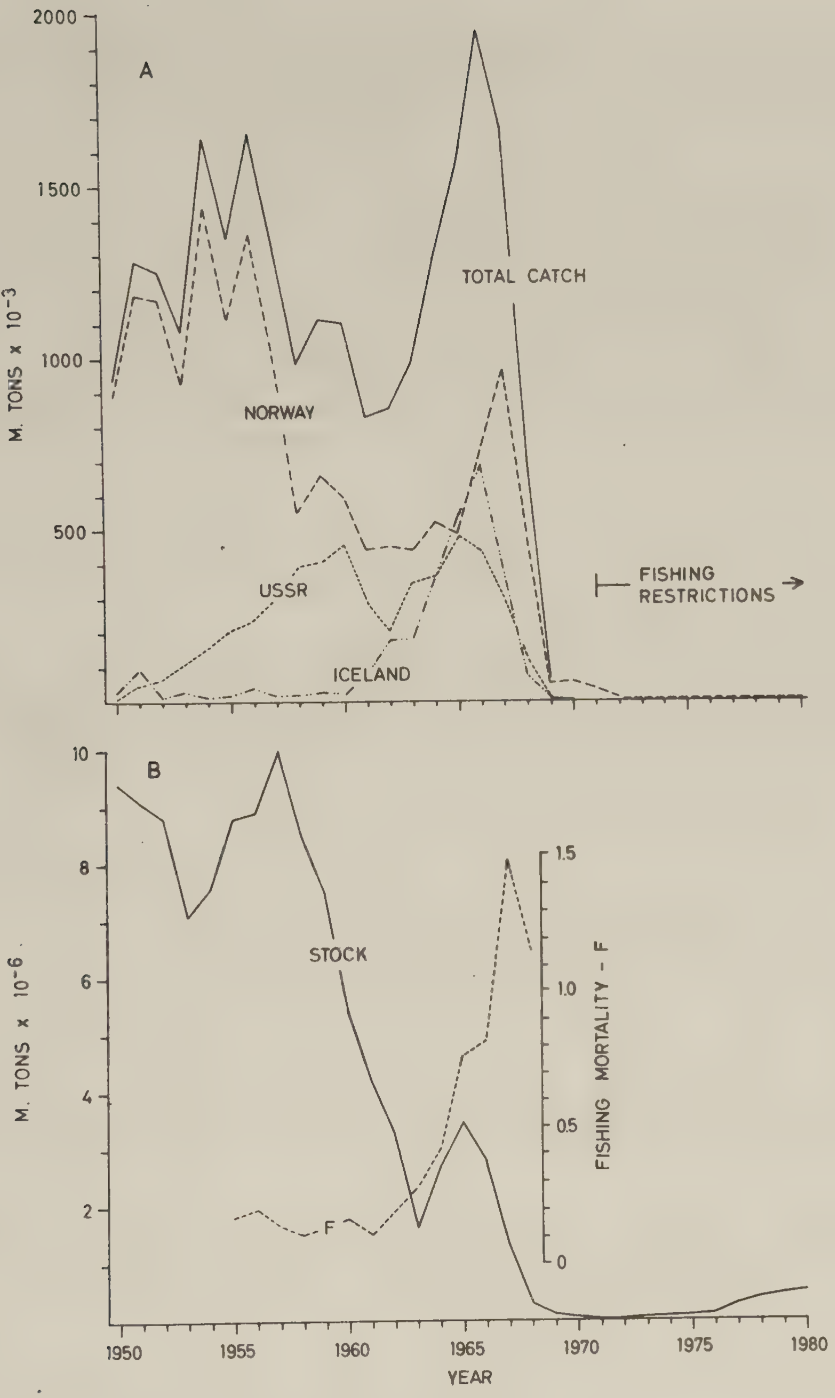

Fig. 2. Norwegian spring spawning herring

A. Annual catch, total and by major fishing nations, demonstrating the increased catch in the late 1960's and the collapse of the fishery by 1970.

B. Biomass of spawning stock (age $\geq$ 5 years) and fishing mortality rate (age $\geq$ 7 years) 1955-1968, showing the stock decline and increased exploitation during the 1960's.

(Data and figure adapted from Dragesund, Hamre and Ulltang 1980, Anon. 1972 and Anon. 1982.)

During the last half of the 1960's the spawning stock declined due to an almost complete lack of recruitment and a continued high exploitation resulting in fishing mortalities above 1.0. By 1970 the stock was reduced to less than 50,000 tons. In the 1970's the stock has increased slowly, and in 1980 it was estimated at 450,000 tons (Anon, 1982). This is only about 5 per cent of the stock size during the early 1950's.

The stock of Norwegian spring spawners was near extinction in the early 1970's, and no effective measures of management were introduced prior to this. Analyses by Dragesund, Hamre and Ulltang (1980) have shown that the collapse of the fishery and the stock occurred as a combined effect of increased effort in the adult fishery and a continuation of high exploitation on the immature stock. An introduction of minimum landing size or other means of protecting 0- and 1-group herring in the 1960's, preferrably also combined with a catch quota on adult fish determined by an optimum fishing mortality, might have prevented overexploitation. It is estimated that by such regulations of the fishery the spawning stock could have remained at a level of 2.4 to 4.7 million tons in 1970.

## Icelandic Spring Spawners

The history of this stock is illustrated by the graphs of Fig. 3 based on data by Jakobsson (1980a).

The Icelandic spring spawning herring were caught by Icelandic vessels both on the north and the south coast of Iceland. As indicated in the previous section the Icelandic spring spawners occurred at times together with the Icelandic summer spawners and the Norwegian spring spawners. Mixed catches were, however, split on stocks on the basis of biological criteria, mainly by scale typing.

A major part of the catch of Icelandic spring spawners was taken on the north coast in summer.

Fig. 3A shows the catch for the years 1950-1980.

During the 1950's the annual catch increased from 20,000 tons to a peak of 270,000 tons in 1962. From then on catches declined, and near zero catches were taken throughout the 1970's.

Fig. 3B shows the changes in the size of the Icelandic spring spawning herring stock and the fishing mortality during the years of stock decline as reported by Jakobsson (1980a).

The spawning stock increased by good recruitment in the early 1950's and reached a peak level of about 800,000 tons in 1957. During the 1960's the stock decreased sharply, and a linear relationship between stock and recruitment was observed (Jakobsson 1980a). By 1970 the stock was virtually extinct and has shown no sign of recovery.

As shown in Fig. 3 increased catches on the declining stock resulted in a marked increase in the fishing mortality during the early 1960's. Prior to 1960 fishing mortalities were very low, in most years less than 0.1. From this level the fishing mortality rose to 1.0-1.7 in the period 1964-1968, and fell again in the late 1960's as there were no herring left to fish.

Jakobsson (1980a) analysed the development of the fishery and the impact on the stock, and evaluated various management strategies which could have been followed. No fishing of 0- and 1-year old herring and catch quotas corresponding to low fishing mortalities would have postponed or prevented the collapse of the stock. It is, however, evident that drastic changes in the environment contributed to the sharp reduction in recruitment in the late 1960's.

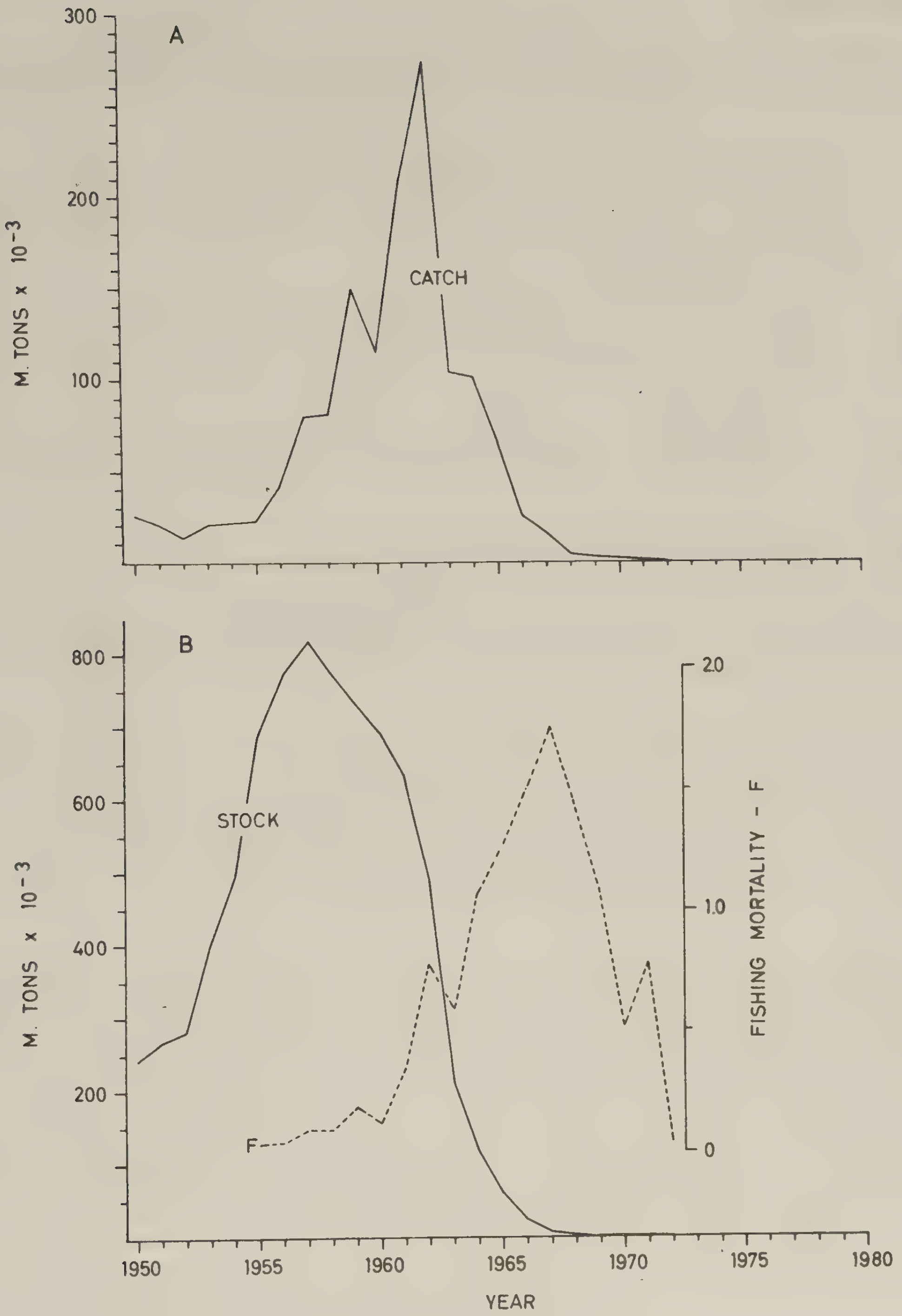

Fig. 3. Icelandic spring spawning herring

A. Annual catch.

B. Biomass of spawning stock (age $\geq$ 4 years) and fishing mortality (weighted mean, age 4-15 years) 1955-1972 illustrating the relationship between stock decline and fishing mortality increase.

(Data from Jakobsson 1980a.)

### Icelandic Summer Spawners

The development of the fishery and assessments of the stock have been described by Jakobsson (1980a). For the most recent years his data are reported to ICES (Anon. 1982) and estimates of stock size from echo surveys 1973-1982 are available (Jakobsson 1982).

Fig. 4A shows the changes in catch during the period 1950-1980. In the 1950's most of the catch was taken on the south coast of Iceland by drift nets in autumn. Purse seining became increasingly important, and from 1960 purse seiners equipped with sonar and power blocks revolutionized the fishery. Catches increased rapidly and exceeded 100,000 tons in the early 1960's.

After 1965 catches declined and regulations in the fishery were introduced. Following a near total ban on fishing in 1972-1974 catches have again increased, and in 1980 about 50,000 tons were allowed to be taken.

Fig. 4B shows the stock changes: a build up period in the 1950's, a decline in the 1960's and new increase during the 1970's. On the figure is also shown the varying rate of exploitation.

Fishing mortalities in the 1950's were low and generally fluctuated between 0.1 and 0.2. In 1960 the situation changed. Fishing mortality increased, particularly on the younger age groups. In 1965 and 1967 the fishing mortality on the mature herring reached 1.2 and 1.5. During the years 1972-1974 purse seining was prohibited and fishing mortalities were negligible. From 1975 the fishing mortality was predetermined and governed the catch quotas in order to allow a rebuilding of the stock.

Stock changes are, of course, not only determined by fishing, but depend also on recruitment. From 1954 to 1963 recruitment was stable and high resulting in an increasing stock. This stock, however, produced small year classes during 1964-1970. In 1971 and 1974 when the stock was at a very low level, relatively good year classes occurred. These year classes, protected by regulations of the fishery, contributed significantly to the spawning stock. Continued good recruitment has resulted in a rapid rebuilding of the stock. At the onset of the 1980's the stock is again at the level of that found in the mid 1960's.

It will be recognized from the descriptions given above that the three stocks of Atlanto-Scandian herring have passed through a rather parallel history from 1950 to 1980. The first decade was characterized by stable or increasing stocks. They were lightly fished by traditional gear near the coast predominately during the spawning period. The overall biomass of the stocks was about 10 million tons yielding catches of about 1 million tons. During the 1960's all stocks declined at a rapid rate. Catches remained high as the stocks were now fished extensively. A new technologically advanced fishing fleet of seiners followed the shoals of herring migrating between spawning areas near the coast and feeding areas in the open sea. At the same time the exploitation changed to include a larger proportion of immature herring. By the beginning of the 1970's all stocks were in a depleted stage. Catches had fallen to a minimum, and management in the way of fisheries restrictions seemed to have come too late. During the 1970's management has aimed at minimizing the fisheries in an attempt to allow the stocks to recover. Such a recovery has been seen for two of the stocks, but the recruitment and the rate of recovery have been different. At present, the total biomass of adult Atlanto-Scandian herring is only about 700,000 tons, and the allowed catch 60,000 tons, i.e. less than 10 per cent of the stock and yield in the early 1950's.

## FISHING FLEETS

The histories of the Atlanto-Scandian herring stocks are linked to the development of the fleet of vessels exploiting the stocks. The escalated exploitation and the decreasing stocks in the 1960's were in general terms a result of technical improvements and increased efficiency of the purse seine fleet.

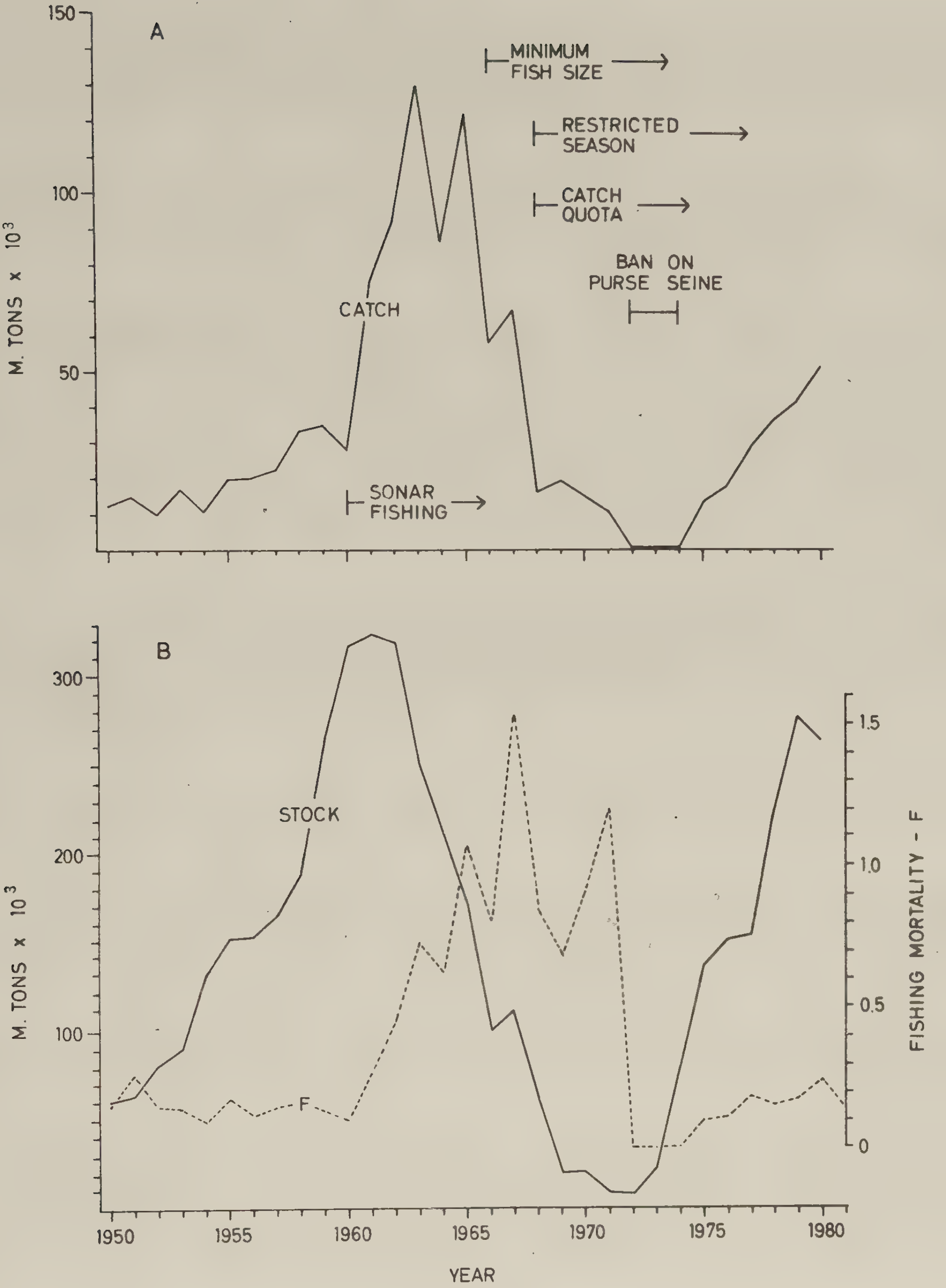

Fig. 4. Icelandic summer spawning herring

A. Annual catch showing the fluctuating yield 1955-1980.

B. Biomass of spawning stock (age ≥ 3 years at the time of spawning) and fishing mortalities (weighted mean, 1950-1959 age 3-10, later age 3-13) reflecting the effects of the unrestricted fishery and the fisheries management of the 1970's.

(Data from Jakobsson 1980a and Anon. 1982.)

The fishing effort in a fishery by purse seiners is difficult to define and measure. For this reason no effort data, suitable to quantify changes in the fishing power, are available. Evidence of such changes can, however, be found in records of the number of vessels participating in the herring fishery together with indicators of altered catching capabilities.

Purse seining has been the most important fishing method in terms of landed catch of Atlanto-Scandian herring over the period 1950-1980. Other gears, mainly nets, accounted for about 40 per cent of the landings in the early 1950's, but fell to less than 10 per cent by 1960.

Fig. 5 shows the changes in number of Norwegian purse seiners during the recent 30 years. Up to 1957 the number increased steadily, and catches of Norwegian spring spawning herring went up at the same rate. In the late 1950's the stock declined (Fig. 2) and the seiners lost the main source of income and ran into an economic crisis. Consequently, the number of seiners in operation fell considerably. At this stage a new development started. Encouraged by the success of technical improvements in Iceland the fleet went through a modernization process and started to fish on the open sea. Fishing shifted from the depleted stock of Norwegian spring spawners in succession to North Sea herring, mackerel and capelin.

By the end of the late 1960's the fleet consisted of about 400 seiners having a cargo capacity of about 100,000 tons (Mietle 1969). In 1969 the fleet landed a total of about 1.5 million tons of herring, mackerel and capelin. The catching capacity was, however, not fully utilized. Given sufficient fish resources, adequate shore facilities and acceptable market conditions landings could possibly be doubled (Bakken and Dragesund 1971).

The evolution of the fishery was a result of a remarkable technological development of the purse seine fishing in the late 1950's and early 1960's. This is illustrated in Fig. 6.

In the 1950's purse seine fishing was carried out by a two-dory method. Half of the net was loaded in each of two dories which shot the net in semi circles. In the beginning of the 1960's the fishing changed to a ring net method. The net was operated from the aft section of the seiner and hauled back by a power block (Hamre and Nakken 1971).

The new system had a series of advantages. Time and labour were saved, larger and deeper nets could be operated, and fishing was less affected by rough weather allowing off shore operation.

Along with this improvement acoustic fish finding instruments, particularly the sonar, came into use (Fig. 6). This greatly increased the ability of the vessels to locate herring shoals. In addition a number of other innovations further increased fishing power; fish pumps, synthetic fibre nets, transverse thrust propellers, lengthened vessels, lifted decks, etc. This resulted in improved earnings which due to the taxation system were reinvested in new vessels, improvements and gears (Mietle 1969).

It seems now clear that the increased fishing power of the purse seine fleet had a determining effect on the stock of Norwegian spring spawning herring. The stock decline came about as a result of increased fishing effort particularly on the younger age groups in the summer and autumn. Ulltang (1976 and 1980) has shown that although the stock decreased the catchability actually increased, since for a schooling fish like the herring a constant fishing effort will generate a constant catch instead of a constant fishing mortality as is usually assumed.

In brief it may seem appropriate to characterize the relationship between the fishing fleet and the stock during the period 1950-1980 thus: in the beginning the livelihood of the fleet was determined by the stock, later the fleet determined the livelihood of the stock.

The development of the purse seine fleet in Iceland was very similar to that of Norway, only that the technological changes occurred earlier and faster. In the late 1950's the Icelandic fleet consisted of close to 250 purse seiners (Jakobsson 1980b).

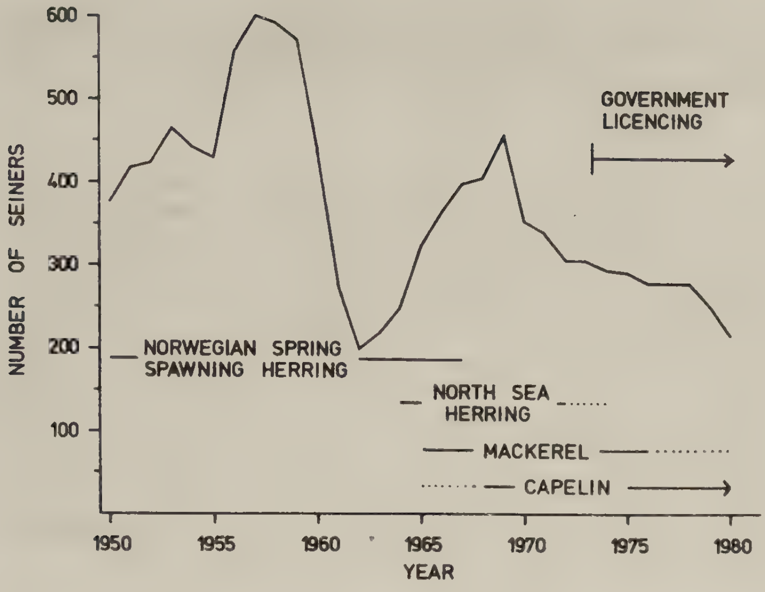

Fig. 5. Changes in the number of Norwegian purse seiners (l.o.a. > 90 feet) with indications of main target species.
(Data by Mietle 1969 and Fishery statistics of Norway.)

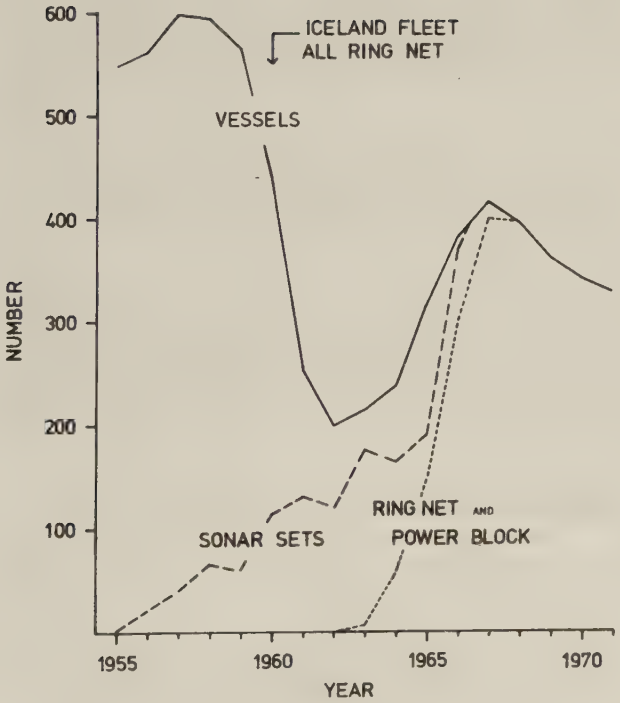

Fig. 6. Technological development in the Norwegian fleet of purse seiners in the 1960's illustrated by the adoption of sonar and the change over from two-dory fishing to the ring net technique in the herring fishery.
(Adapted from Bakken and Dragesund 1971.)

During the 1960's the number was reduced, but as for the Norwegian vessels the fishing power increased due to the technological improvements. The sonar guided ring net method by power block had replaced the two-dory fishing by about 1960 (Jakobsson 1980b). At the end of the 1960's the number of purse seiners were reduced to about 100, and during the next 10 years further to about 50.

It may be concluded that also for the Icelandic stocks the fishery played a decisive role in reducing the stock size. The Icelandic spring spawners, however, could be considered as a stock of Atlanto-Scandian herring living at the outer limits of its distribution (Jakobsson 1980a), and shifts in environmental conditions seem to have contributed significantly to stock changes. In the stock of Icelandic summer spawners the rate of decline was reduced, but not halted, due to restrictions in the purse seine fishery.

## BIOLOGICAL CHANGES

In association to changes in the abundance of Atlanto-Scandian herring the general biology of the stocks has also changed, e.g. distribution, migration, spawning and growth.

In the 1950's the Norwegian spring spawners were feeding in the Norwegian Sea northeast of Iceland towards the island Jan Mayen, overwintered east of Iceland and migrated from this area eastwards to extensive spawning grounds along the west coast of Norway (Fig.1). As the adult stock was reduced in the 1960's, the area of distribution shifted northwards, north of Jan Mayen, with a new overwintering area off northern Norway. The area of spawning diminished, and the most important grounds were found on the coast of northern Norway.

In the early 1970's the adult stock was minimal, and spawning was not observed. Restrictions in the fishery protected the 1969 year class. This year class spawned at an early age, in 1973, mostly on the coast of northern Norway. After spawning the herring did not migrate to the open sea, but remained along the coast during the feeding period in summer. In this way the life history and migration pattern of the stock was totally changed (Dragesund, Hamre and Ulltang 1980).

In later years, the stock has remained in coastal waters split in a northerly and a southerly component having separate spawning grounds. Recruitment has been low, and the slight increase in stock size (Fig. 2) is mainly due to an increase in the southern component (Anon. 1982).

The observed individual growth rate in the 1970's has been significantly higher than that of the 1950's. As example, an 8 year old herring of the 1969 year class reached a length of 36.5 cm while the average length at the same age during the 1950's and 1960's was about 34 cm. Along with this the mean age of maturity has been reduced from 6-7 in the 1950's to 4 years in the 1970's (Hamre, pers. comm.).

Changes have also been observed in the migration pattern of the Icelandic summer spawners, particularly in the timing of the southward migration from the feeding area to the overwintering area off southern Iceland. The migration starts earlier, and the stock now remains during winter in dense shoals close to the shore in restricted localities on the south coast (Jakobsson 1982).

In the previous section it was pointed out that the disappearance of the Icelandic spring spawners seem to have been associated with adverse enviornmental conditions: low sea temperatures and absence of zooplankton to feed on. Conditions improved after the collapse of the stock (Jakobsson 1980b), but Icelandic spring spawners are now only recorded as an insignificant admixture to the Icelandic summer spawners.

Catch statistics and records of the fisheries on Norwegian spring spawners from early 1800 indicate wide fluctuations, and suggests that the recent situation of extremely low stock level is not unique. An hypothesis of alternation in spawning grounds and natural cycles of fluctuating abundance caused by biotic factors was put forward by

Devold (1963). The investigation and analyses of later years indicate that the hypothesis must be rejected, but the concept of stock components seems verified.

## MANAGEMENT

Saetersdal (1980) has reviewed the management history of the Norwegian spring spawning herring along with other pelagic fish stocks.

The collapse of the Norwegian spring spawning stock (Fig. 2B) was a very dramatic event, but it attracted surprisingly little attention from the scientific community at the time. In 1965 the Liaison Committee of ICES reported to the Northeast Atlantic Fisheries Commission (NEAFC) as the responsible international management body that the stock was declining. The decline was, however, assumed to have natural causes and no action was taken. Even as late as 1970, after the fishery had completely collapsed, the scientific advice was insubstantial: "...reduce the mortality rate on immature herring and avoid further increase in fishing rate on the adult stock". Not until 1975 was a complete ban on fishing recommended.

It seems that the stock events were, at least in part, recorded by the scientists during this period, but the significance was not realized, and no effective management action was taken until too late. To some extent this can be attributed to the system of fisheries management in the 1960's, since a consensus of several fishing nations was required in order to obtain effective regulations.

The management of the Icelandic stocks, meaning restrictions in the fisheries, came in force at a somewhat earlier stage of the stock decline. In 1966 a minimum legal size of landed herring was introduced, advice (Jakobsson 1980a) was given on a maximum catch quota and closed seasons (Fig. 4). The recommendations were gradually accepted, but in general, they were enforced too late to halt the stock decline, and the Icelandic spring spawners were depleted before effective action was taken.

After 1970 the biological monitoring and, based on this, the established system of strict management has been of prime importance for the rebuilding of the Icelandic summer spawning stock.

In the present situation the management objective is to rebuild the herring stocks. To achieve this the authorities have no option but to attempt to balance the interest in a rapid rate of stock increase to the demands of allowing a fishery for socio-economic reasons. This is particularly the case for the Norwegian spring spawners for which the long term annual yield of a rebuilt stock would be at least 1.5 million tons.

The future of the Icelandic spring spawner cannot be expected to be determined by any form of management. A re-establishment of this herring appear to be dependent on the development of the Norwegian spring spawning stock as Jakobsson (1980a) has suggested that the stock will not recover without immigration.

## ACKNOWLEDGEMENT

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*NORTH EAST ATLANTIC - ATLANTICO NORDORIENTAL*

# ON THE BIOLOGY AND CHANGES IN EXPLOITATION AND ABUNDANCE OF THE ICELANDIC CAPELIN

by

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## Resumen

Se describe la biología y explotación del capelán que habita las aguas entre Islandia, Groenlandia y Jan Mayen. Se describen, asimismo, y se discuten los efectos aparentes de la pesca y las acciones de ordenación.

## INTRODUCTION

The capelin, *Mallotus villosus* (Müller), is a boreoarctic, pelagic and schooling, salmonid species with a more or less circumpolar distribution. Although capelin seldom grow larger than 20 cm in size and are short lived (3-5 years) their biomass in certain areas may reach millions of tonnes.

Capelin is a highly significant item in the diet of many commercially important northern fish species. Although feeding in arctic waters it may transfer large amounts of biomass and energy to warmer areas, which it periodically visits for example, in order to spawn, thus becoming available as food for larger fish such as the cod.

The largest known stock of capelin inhabits the Barents Sea and adjacent waters while smaller but nevertheless important stocks are found off Iceland, Greenland, Newfoundland and Labrador as well as in the North Pacific.

During the last 2-3 decades capelin have become an important source of raw material for the production of meal and oil and lately on a smaller scale for human consumption. Because of its short life span and pelagic schooling nature capelin have fallen easy prey to modern fishing technology and stocks have collapsed because of overfishing.

The present paper deals with Icelandic stock of capelin which inhabits the area between Iceland, Greenland and Jan Mayen. The biology of this stock is outlined as well as its exploitation and the apparent effect of the fishery as well as management actions are described and discussed.

## ICELANDIC CAPELIN

### Spawning times and areas

The Icelandic capelin spawn on the seabed in shallow coastal waters mainly during the second half of March and the first half of April. Usually the spawners migrate clockwise from North to Southeast Iceland the first arriving at the southeast coast in late January or February. In some years spawners also arrive at the southwest coast of Iceland directly from the banks off the northwestern peninsula in February-March. In both cases spawning usually begins about 2-3 weeks after the fish entered the warm coastal waters.

The main spawning area extends from Southeast Iceland along the south coast to the Snaefellsnes peninsula in the west. The bulk of the south and west coast spawning is usually finished by mid-April.

Spawning also takes place off the north and northwest coasts of Iceland. This is a less important and later spawning which may last throughout May into June.

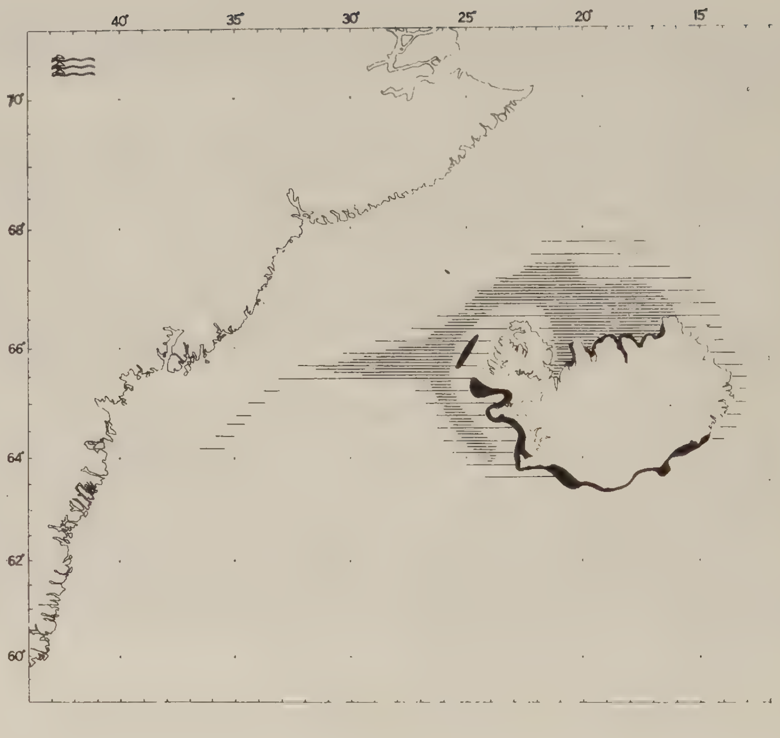
The spawning areas of the Icelandic capelin are shown in Figure 1.

### Distribution of larvae

After hatching the larvae ascend towards the surface waters and are transported by currents to the west and north of Iceland. In some years a westward drift across the banks to the north of the Irminger Sea basin towards Greenland is observed. The system of surface ocean currents in the Iceland-Greenland-Jan Mayen area is shown in Figure 2.

The distribution and abundance of capelin larvae in the Iceland-Greenland area have been studied annually in August since 1970. A schematic representation of the results of these investigations is shown in Figure 1.

Fig. 1.
Spawning areas (black) and general larval distribution in August (shaded) of the Icelandic capelin.



## Distribution and migration of 1-3 group capelin

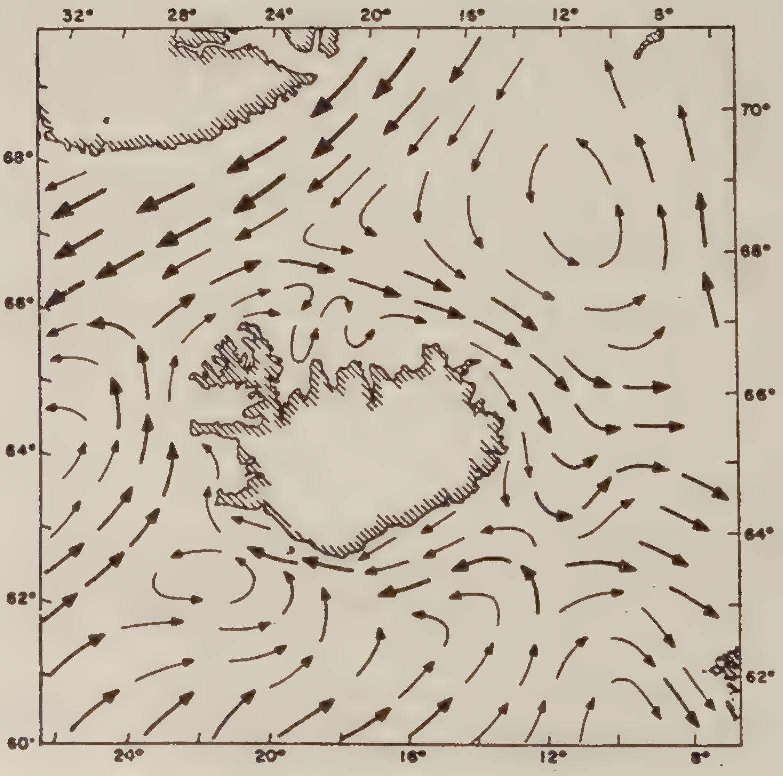
Through extensive acoustic surveying and sampling, first in connection with scouting for the fishery and later for stock assessment purposes, the migrations of the Icelandic capelin have been mapped and may be described as follows:

In winter juvenile 1-2 group capelin are most frequently found in waters over or near the continental shelf off North and Northwest Iceland, but sometimes also further east.

In spring a varying proportion of this stock component migrates out into deeper and colder waters to feed during the summer months. Thus, at that time of the year, it may also be recorded in deep waters between Iceland and Greenland and over the East Greenland plateau from the Scoresby Sound south to the Dohrn Bank. Juvenile capelin, probably belonging to the stock which spawns at Iceland, have also been recorded further west, particularly at the edge of the continental shelf off the Angmagsalik Bay.

In autumn and early winter the immatures retreat with the advancing cold waters from the north and overwinter off Northeast and North Iceland or in the Denmark Strait area (NW-Iceland) as the case may be.

Fig. 2.
Surface ocean currents in the Iceland-Greenland-Jan Mayen area (after Stefánsson 1962).



Maturing 2-3 group capelin exhibit a somewhat similar behaviour pattern but as a rule have a much wider distribution. Thus, most of these capelin migrate to the deep and colder regions in spring and early summer. In recent years the maturing stock has been divided in two parts during the feeding season which we may refer to as northern and southern components.

The southern component feeds in the Denmark Strait and off North Iceland and is often mixed with juveniles. The northern component, consisting of the oldest and largest fish, undertakes a long northward migration to the area between Greenland and Jan Mayen and to the north of Jan Mayen to 72-73$^{O}$N. These capelin stay out of the distribution area of the juveniles for at least 2-3 months in summer and autumn.

Toward autumn both components of the maturing stock start migrating back south and together gradually assemble on the overwintering grounds off North or Northwest Iceland in October-November. From there the main spawning migration begins in December-January and follows the edge of the continental shelf off North and East Iceland until the fish meet the warm Atlantic water when they turn westwards towards the southeast coast. These movements of the maturing stock were very clearly demonstrated during a tagging experiment in 1978/79 (Figure 3).

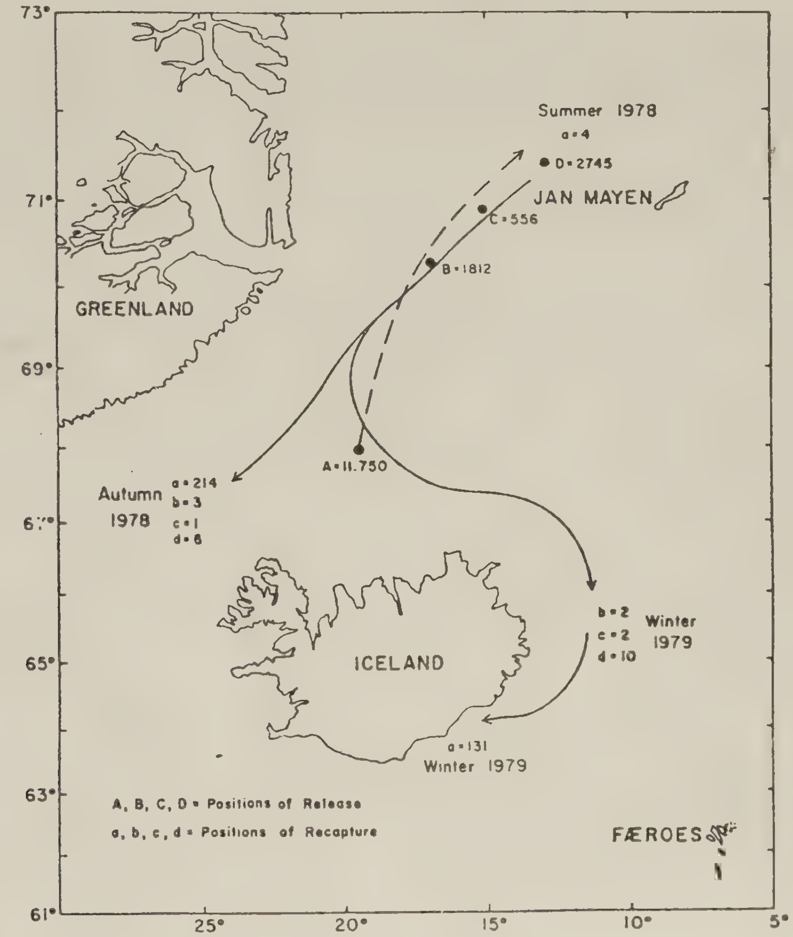

73°
71°
69°
67°
65°
63°
61°
25°
20°
15°
10°
5°
Summer 1978
a = 4
D = 2745
JAN MAYEN
C = 556
B = 1812
GREENLAND
A = 11.750
Autumn 1978
a = 214
b = 3
c = 1
d = 6
b = 2
c = 2
d = 10
Winter 1979
ICELAND
a = 131
Winter 1979
A, B, C, D = Positions of Release
a, b, c, d = Positions of Recapture
FÆROES

Fig. 3.
Migration routes of adult capelin as indicated by tag returns. Summer 1978 - winter 1979.

In those years when capelin arrive to spawn off West Iceland from the north and northwest, a part of the spawning stock stays in the overwintering area off Northwest Iceland until late February when its southward migration begins.

The distribution areas of juvenile and adult capelin are shown in Figure 4 and the general migration pattern of the maturing stock in Figure 5.

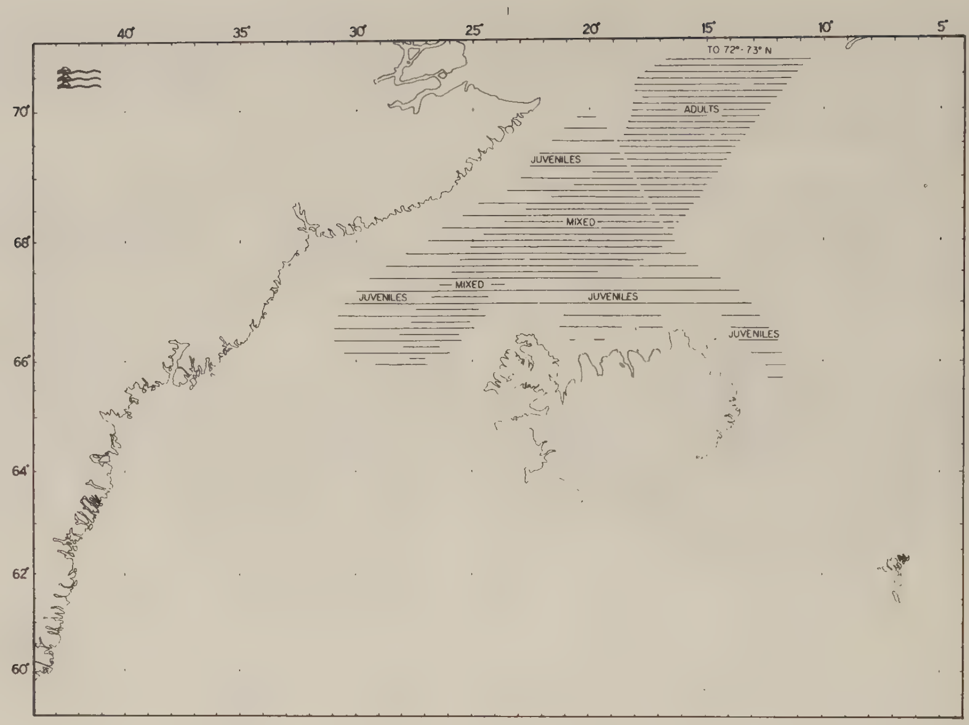
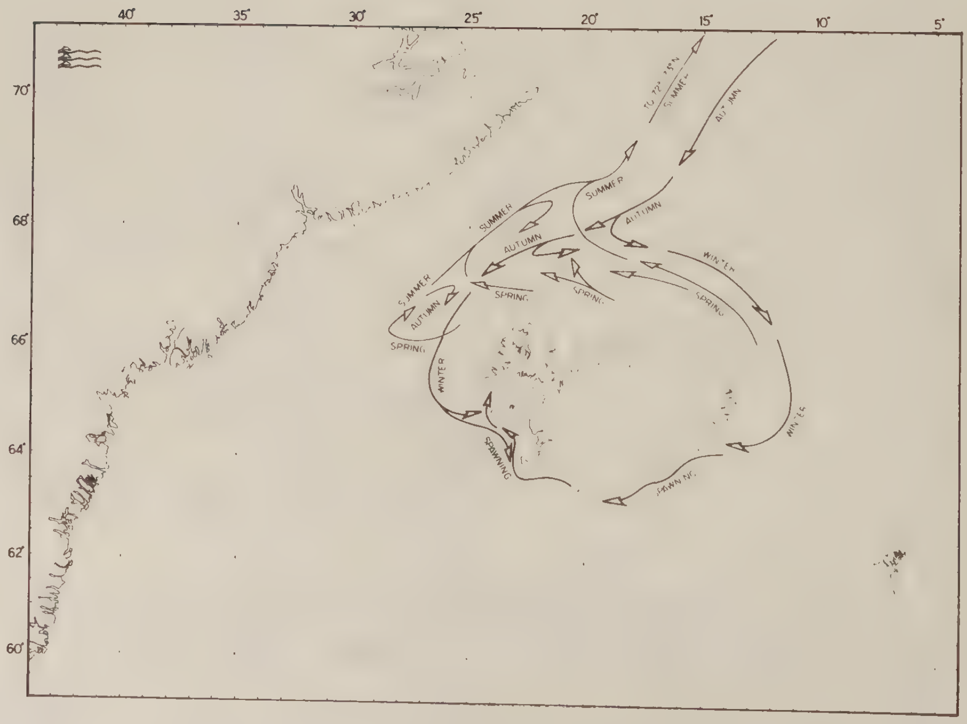

40°
35°
30°
25°
20°
15°
10°
5°
70°
68°
66°
64°
62°
60°
TO 72°-73° N
ADULTS
JUVENILES
MIXED
MIXED
JUVENILES
JUVENILES
JUVENILES

Fig. 4.
A generalized representation of the distribution areas of juvenile and adult capelin in the feeding season.


40°
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5°
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66°
64°
62°
60°
TO 72°-73°N
SUMMER
AUTUMN
SUMMER
SUMMER
AUTUMN
AUTUMN
WINTER
SPRING
SPRING
SPRING
SUMMER
AUTUMN
SPRING
WINTER
SPAWNING
SPAWNING
WINTER

Fig. 5.
The general migration pattern of the maturing stock.

## Age and mortality at spawning

Most of the Icelandic capelin spawn as 3 year olds. A varying proportion of each year class does, however, not mature until one year later. Thus, the spawning stock consists of two age groups where the ratio of 3 and 4 year old spawners varies somewhat depending on feeding conditions and relative year class strength. In later years the ratio of 4 year old fish has been unusually low which possibly is connected with the changes in fishing pattern and mortalities brought about by the recent advent of a summer and autumn fishing season.

On the other hand the survival rate of spawners is considered very low and second time spawners do not seem to contribute to the spawning stock. This is for example, borne out by the consistently low percentage of the older age group in the spawning stock even though a large year class has spawned as three year olds in the year before. Without risking oversimplification it seems that for practical purposes the survival may be set at zero.

## THE FISHERY

The total annual catch from the Icelandic capelin stock by season and countries for the period 1964-82 is shown in Table 1. Prior to this period capelin belonging to the Icelandic stock were only caught for bait and the catch amounted to no more than a few hundred tonnes a year.

Table 1: The total annual and seasonal catch of capelin in the Iceland, E-Greenland, Jan Mayen area (in '000 tonnes).

| Year | Winter season | | Summer and autumn season | | | | Total |
|---|---|---|---|---|---|---|---|
| | Iceland | Faroes | Iceland | Norway | Faroes | EEC | |
| 1964 | 8.6 | | | | | | 8.6 |
| 1965 | 49.7 | | | | | | 49.7 |
| 1966 | 124.5 | | | | | | 124.5 |
| 1967 | 97.2 | | | | | | 97.2 |
| 1968 | 78.1 | | | | | | 78.1 |
| 1969 | 170.6 | | | | | | 170.6 |
| 1970 | 190.8 | | | | | | 190.8 |
| 1971 | 182.9 | | | | | | 182.9 |
| 1972 | 276.5 | | | | | | 276.5 |
| 1973 | 440.9 | | | | | | 440.9 |
| 1974 | 461.9 | | | | | | 461.9 |
| 1975 | 457.6 | | 3.1 | | | | 460.7 |
| 1976 | 338.7 | | 114.4 | | | | 453.1 |
| 1977 | 549.2 | 25.0 | 259.7 | | | | 833.9 |
| 1978 | 468.4 | 38.4 | 497.5 | 154.1 | | | 1158.4 |
| 1979 | 521.7 | 17.5 | 441.9 | 126.0 | 2.5 | | 1109.6 |
| 1980 | 392.0 | | 367.2 | 118.6 | 24.4 | 14.3 | 916.5 |
| 1981 | 156.0 | | 484.6 | 91.4 | 16.2 | 20.8 | 769.0 |
| 1982 | 13.0 | | | | | | 13.0 |

In the mid-sixties Iceland started a capelin fishery for a reduction to meal and oil. This was a purse seine fishery and carried out by the local herring fleet outside the traditional herring season.

Until 1973 the capelin fishery was limited to coastal waters during the spawning season from late February to April. But with the depletion of the Atlantic-Scandian herring stocks in the late sixties and the North Sea herring in the seventies the capelin fishery gained momentum and importance.

By 1969 almost all the Icelandic herring fleet had become involved in the winter capelin fishery and it soon became obvious that processing facilities scattered along the N-Icelandic coastline, were a limiting factor. Thus, the catch did not exceed 200,000 tonnes during the 1969-71 period.

In the 1972 winter season a coordinating body, the Capelin Board, was set up in order to synchronize fishing and production. This was mainly done by dividing the coastline into price zones the boats getting higher prices for longer trips. This system had the immediate effect of increasing the catch by about 50 percent as compared to the average for the previous 3 years. The price zone system was operated until 1979 when it was discontinued, the board from then on mainly functioning as collector and distributor of information on catch statistics, available landing spaces and waiting time in the various ports where the factories were located.

As early as 1969 research had indicated that, at least in some years, capelin could easily be caught in January and February when the spawning migration still was in deep waters off East and Northeast Iceland. Such a fishery was attempted in 1970. Difficulties were encountered by the fishing fleet and another attempt was not made until 1973. This time success was immediate and the winter catch jumped to 440,000 tonnes.

With the exception of 1976 when the fleet went on a lengthy strike because of a price dispute the annual catch during the 6 year period 1973-1979 ranged between 440,000 and 575,000 tonnes. Since then the winter fishery has been subject to increasively severe restrictions ending in a total fishing ban in 1983. Apart from a limited Faroese participation in 1977-79 the winter fishery has been conducted by Iceland alone.

In 1975 an attempt was made to catch capelin on the feeding grounds north of Iceland in July and August. At that time there was much drift ice in the area and the experiment failed.

A summer fishery was again attempted in the following year and was an immediate success. The catch amounted to 115,000 tonnes in spite of the fact that most of the fishing fleet was occupied in the North Sea herring fishery that summer and autumn. During the 6 year period 1977-81 the average Icelandic summer and autumn capelin catch has been about 410,000 tonnes taken by about 50 vessels.

The number of Icelandic vessels participating in the capelin fishery is shown for the period 1973-82 in Table 2. It must be stressed, that in this case the number of fishing boats is no measure of effort. The increase in size of vessels and fishing gear and technological improvements in the acoustic search systems more than make up for the reduction in the number of vessels participating in the winter fishery during the above period.

Table 2: Changes in numbers of Icelandic capelin vessels during the 10 year period 1973-82.

| Year | Winter season | Autumn season |
|---|---|---|
| 1973 | 90 | - |
| 1974 | 136 | - |
| 1975 | 107 | 3 |
| 1976 | 86 | 29 |
| 1977 | 88 | 39 |
| 1978 | 82 | 56 |
| 1979 | 65 | 52 |
| 1980 | 51 | 52 |
| 1981 | 52 | 52 |
| 1982 | 8 | 0 |

In the summer of 1978 the Norwegian capelin fleet started a purse seine fishery on that part of the stock which migrates to feed in the area between Jan Mayen and Greenland. The catch during that first season was 154,000 tonnes but has since been subject to restrictions agreed upon with Iceland which, for her part, has mainly reduced the winter catch as stated previously.

In 1980 and 1981 vessels from the Faroes and EEC countries, mainly Denmark, caught about 40,000 tonnes each year lending an international atmosphere to the capelin fishery in the Iceland-Greenland-Jan Mayen area.

Apart from 13,000 tonnes caught during the 1982 winter season there was a complete fishing ban on fishing from the Icelandic capelin stock in 1982 as well as during the 1983 winter season.

## STOCK ABUNDANCE

Because of the capelin's short life span and spawning mortality large and sudden changes in stock abundance may be expected. For the same reasons researches have to resort to direct, fishery independent methods in order to assess stock size and changes therein.

Comparative measurements of the abundance of 0-group capelin have been obtained in August annually since 1972 (Figure 6). This information has been collected by a combination of sampling by conventional and acoustic methods and is intended to serve as a rough index of recruitment. During the period 1972-75 the 0-group index indicates a high level of recruitment followed by a sharp downward trend and a much lower and decreasing level during the last 5-6 years.

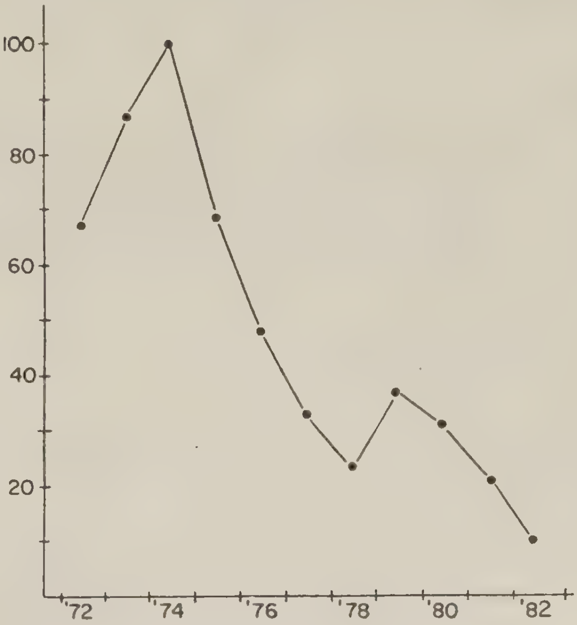


Fig. 6. 0-group indices 1972-1982.

In the seventies several tagging experiments were carried out in order to evaluate the size of the Icelandic capelin stock (Vilhjálmsson and Reynisson, 1979). The marking was done with internal steel tags which were recovered by means of magnets in the processing plants ashore. Because of the small size of the fish the mortality of juvenile capelin proved very high and returns of tags from such taggings were extremely low.

The tagging of adult capelin was, on the other hand, successful and results of estimates of the 1979 spawning stock abundance from the returns were on a similar level as those obtained by the acoustic method. Although tagging apparently can give information on the size of the maturing stock, final results do not become available until during or after the spawning season and consequently are of little value for current management purposes.

Echo surveying of capelin at Iceland has been conducted since the mid-sixties. The main purpose used to be to chart the distribution and movements of the stock as well as to study the behaviour of the fish and so to help the fishing fleet in catching the capelin. With the rapid increase in catches following the advent of the multinational summer and autumn fishery the need for an accurate assessment of the abundance of the stock became of paramount importance.

Due to the information collected during the above scouting cruises it was possible to pinpoint the times of the year during which information on stock abundance most likely could be obtained by acoustic methods. The main requisitions were relatively limited area of distribution and minimum danger of interference by drift ice, weather, other scatterers and bottom echoes. For the maturing or fishable part of the stock the choice was the autumn period when the capelin were in the process of or had assembled on the wintering grounds off North and Northwest Iceland and also during the earlier stages of the spawning migration before the spawners entered the shallow waters at the southeast or southwest coasts of Iceland.

Since 1978 the stock has been surveyed jointly by Iceland and Norway in October, the Icelandic Marine Research Institute carrying out an additional survey in November 1981 when the October survey failed because of adverse ice conditions. In addition Iceland has carried out annual surveys of the abundance of the same spawning stocks in January/ February 1979-1983 for comparison to the autumn estimates.

The basic technique was described by Nakken and Dommasnes (1975) and the variant adopted for the Icelandic capelin stock by Vilhjálmsson _et al_. (1982). A summary of the technique is as follows:

Echo intensities from fish are registered continuously from the depth column along the ships' track and the values obtained integrated and recorded as average/nautical mile for each 5 nautical miles sailed. Trawling is undertaken when necessary in order to ensure adequate biological sampling and to check changes in the echo recordings. In all instances a Simrad 38 kHz acoustic system has been used.

The survey area was divided into suitable subareas depending on variations in the length composition of the capelin as observed from the trawl catches. The integrated echo intensity was converted to fish densities using the equation:

$$N = C \times M \times A$$

Where:

$\underline{N}$ is the total density in terms of numbers,
$\underline{C}$ is the number of capelin per unit area and dependent on mean length of the fish and instrument characteristics,
$\underline{M}$ is the mean integrated echo intensity for the relevant subarea (mm ref. 40 dB gain on echo integrator),
$\underline{A}$ is the subarea measured in square nautical miles.

The sum of the number of fish calculated for each subarea then gives the total stock size in number.

The reference C value had been previously established for the instrumentation of the Norwegian research vessel G.O. Sars and used in abundance surveys of the Barents Sea capelin. In the course of the surveys an intercalibration of vessels has generally been done in two different ways:

1. Calibration with a standard reference target (Foote _et al_., 1981) simulating echo intensity over 1 nautical mile. This served as a check of the C value as well as giving an inter-ship relation irrespective of transducer directivity.

2. Inter-ship calibration on a scattering layer of mostly 0-group capelin and plankton thus including the directivity of the transducers.

The performance of the acoustic instrumentation of the vessels employed has always been remarkably similar and consistent. Examples from October 1982 are shown in Figures 7 and 8.

Fig. 7.
Intercalibration on 0-group capelin and plankton recordings. R.V. G.O. Sars and R.V. Bjarni Saemundsson, 21 October 1982.

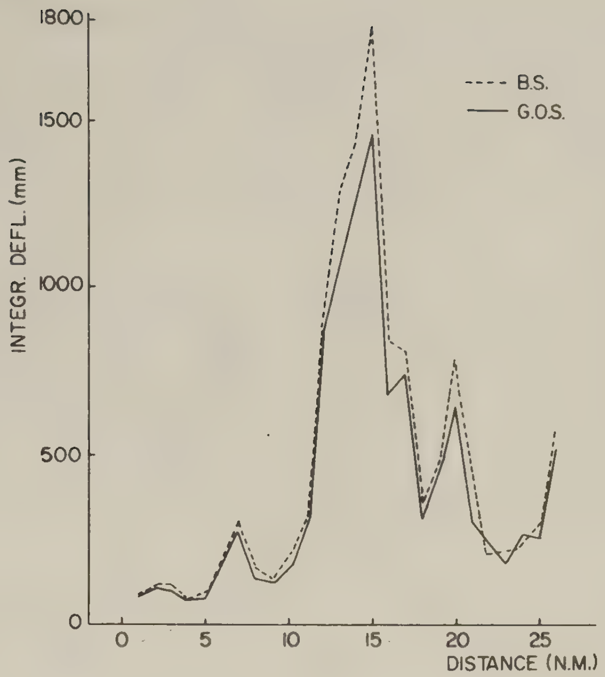
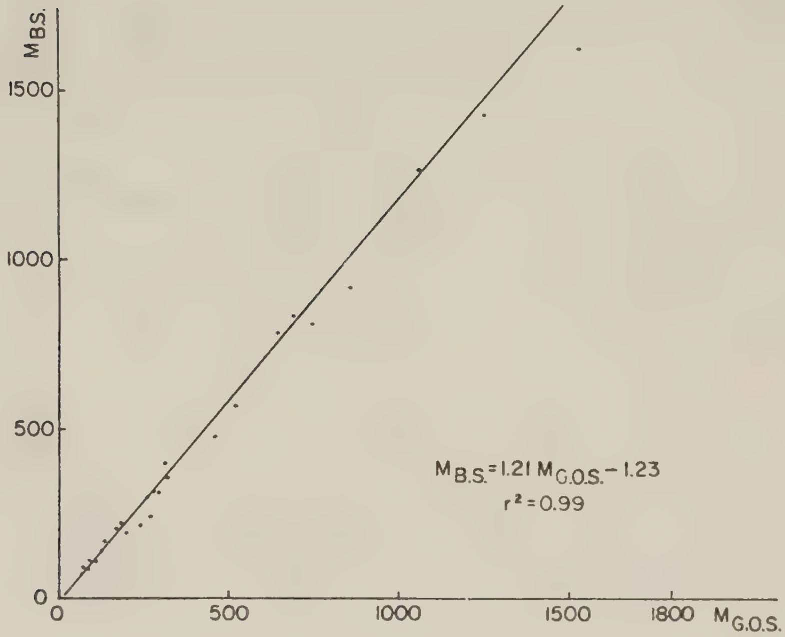


Fig. 8.
The regression line from the intercalibration shown in Figure 7.



Although it is known that the northern component of the stock feeding in the Jan Mayen-Greenland area does not always return to the wintering grounds until November the joint 2 ship autumn surveys have generally been scheduled for the first 3 weeks in October. The reason for this is of course the need for an assessment of the fishable stock abundance as early as possible. With the exceptions of an attempt during the period 25 September - 5 October 1979 as well as of the joint autumn survey in 1981, which had to be repeated in November because of adverse ice conditions, the October surveys have been successful. Examples of a recent survey grid and fish distribution are shown in Figures 9 and 10.

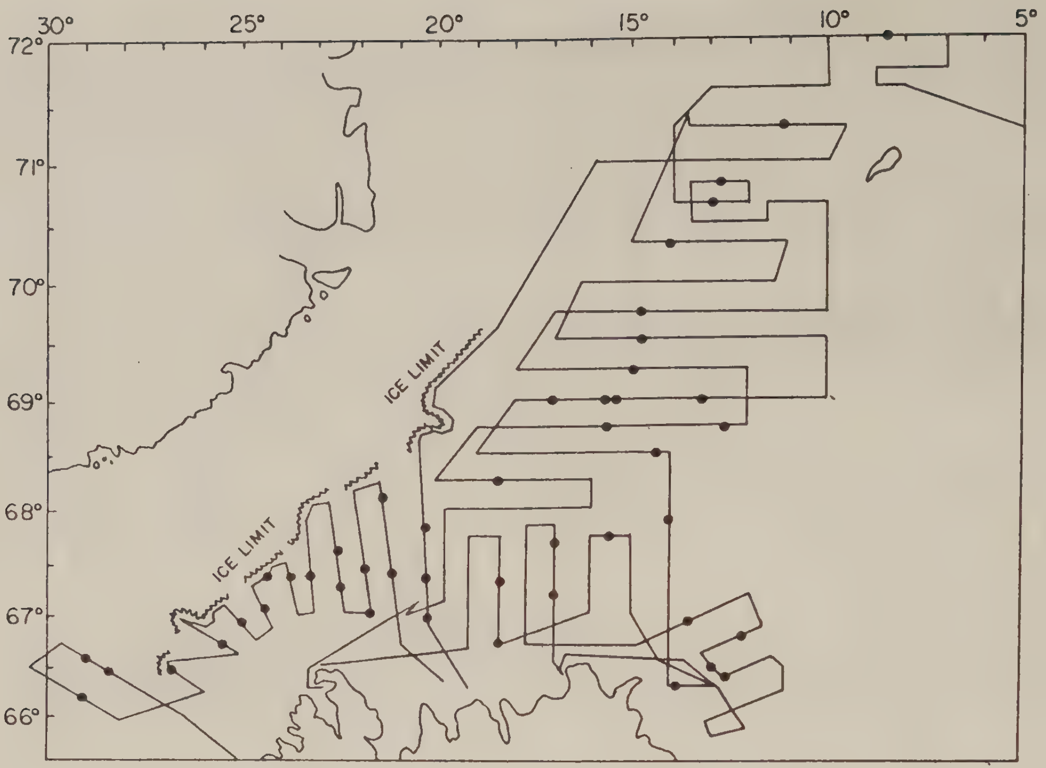

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Fig. 9. Survey grid and trawl stations, 2-20 October 1982.

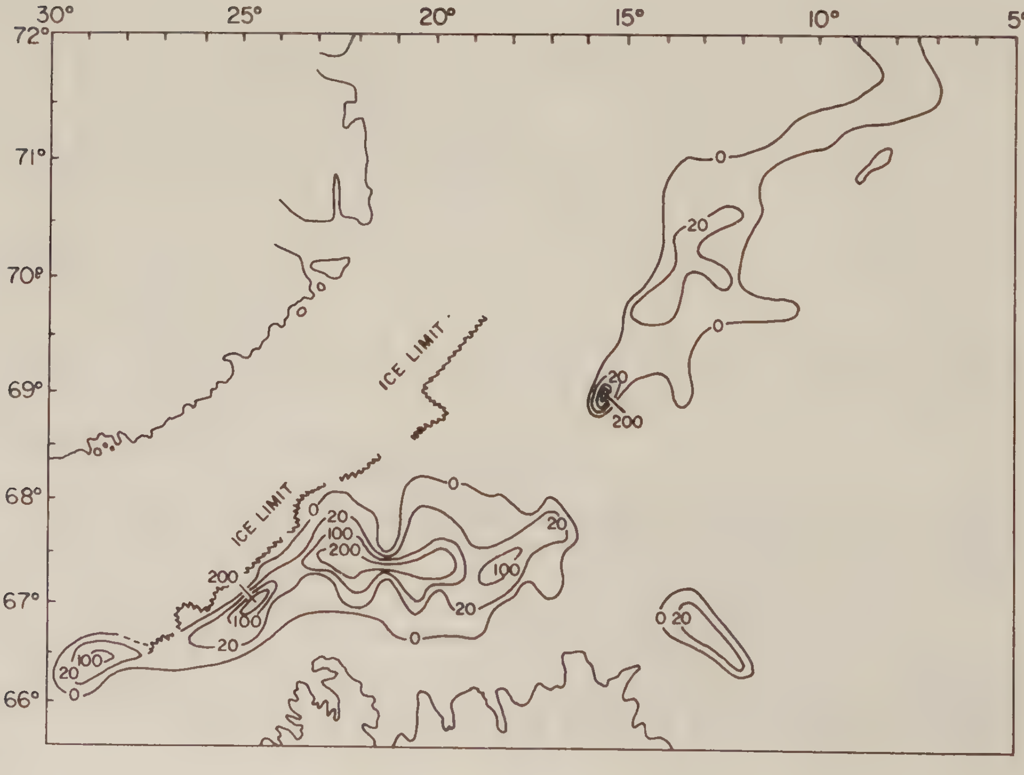
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Fig. 10. The distribution and relative abundance of capelin, 2-20 October 1982.

The Icelandic surveys in January-February have been carried out with 1-2 ships at the time when the spawning or fishable stock normally has a small distribution area, the location of which may vary considerably from one year to another. After having located the stock through rough scouting the actual assessment can, therefore, be carried out in a very short time period. However, weather conditions in the Icelandic area can often be difficult for acoustic surveying. When the stock has been located considerable time has on several occasions been spent in waiting for a suitable opportunity. The reward has been that acoustic assessments were carried out under good conditions and the results obtained credible.

The results of the acoustic estimates of the 1979-1983 spawning stocks are shown in Figure 11. The points on the top line represent the results from the October-November surveys and those on the second line estimates of the abundance of the same spawning stocks obtained in January-February in the following year. When account has been taken of the catch and natural mortality during the intervening period there appears a small but consistent difference between the above sets of stock abundance estimates. On average for the 1979-1983 period this difference is in the order of 5-15 percent with the higher estimate on all occasions being obtained during the January-February surveys.

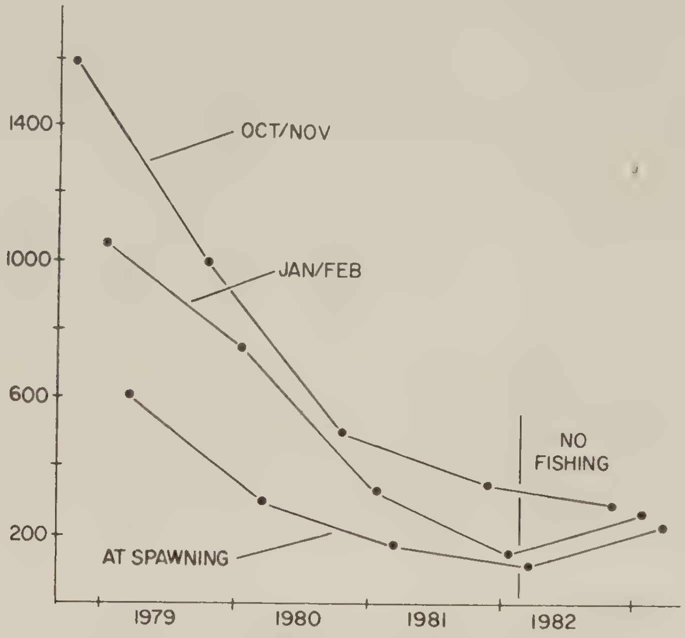

Fig. 11.
Changes in abundance of the spawning stock of the Icelandic capelin as estimated by the acoustic method.

On several occasions it has proved possible to survey the spawning stock component 2-3 times within a very short time interval (10-30 days) as shown in Table 3. The differences within such series of estimates have usually been small and thus established confidence in the applicability of the method to the mature stock. When important deviations were observed they were immediately explainable. Cases in point are survey II in October 1978 when a short spell of windy weather lowered the abundance estimate and surveys I and II in January 1981 when cruise tracks were much too widely spaced with respect to the highly variable distribution density observed at the time.

The results of acoustic estimates of the abundance of the spawning or fishable stock of the Icelandic capelin are, therefore, considered accurate at least in a relative if not the absolute sense and show an alarming decline in stock size during the 1978/79-1982/83 period.

As yet it has proved difficult to assess the abundance of juvenile 1-2 group capelin. The reason for this is the frequent distribution of this stock component in or near areas periodically covered by drift ice. With the advancing of the ice border in autumn, part of the juvenile stock often becomes inacessible and therefore not accounted for during the October surveys. This is indeed suggested by the highly variable occurrence of the juveniles in these surveys. A similar situation is encountered in winter. Recent surveying in late August has, however, brought promising results but further experiments are needed.

Table 3: Comparison of survey results for 5 different stock components. Number x $10^{-9}$ and weight x $10^{-3}$ tonnes.

| NW-Iceland | 1974 | | 1975 | | 1976 | | Total | |
|---|---|---|---|---|---|---|---|---|
| 16-29 Oct. 1978 | N | W | N | W | N | W | N | W |
| Survey I | 0.4 | 13.6 | 20.5 | 548.5 | 50.5 | 944.7 | 71.4 | 1506.5 |
| " II | 0.3 | 10.6 | 16.0 | 426.8 | 39.3 | 734.8 | 55.6 | 1172.2) |
| " III | 0.5 | 17.0 | 22.6 | 603.4 | 55.4 | 1036.1 | 78.5 | 1656.5 |
| E-Iceland | 1974 | | 1975 | | 1976 | | Total | |
| 1 - 7 Feb. 1979 | N | W | N | W | N | W | N | W |
| Survey I | 0.4 | 1.7 | 3.1 | 77.8 | 23.2 | 457.0 | 26.7 | 536.5 |
| " II | 1.0 | 3.1 | 3.2 | 80.3 | 24.0 | 472.8 | 28.2 | 556.2 |
| " III | 1.0 | 2.3 | 3.4 | 85.3 | 25.7 | 506.2 | 30.1 | 593.8 |
| NW-Iceland | 1974 | | 1975 | | 1976 | | Total | |
| Feb. 1979 | N | W | N | W | N | W | N | W |
| Survey I | - | - | 4.6 | 107.0 | 28.3 | 495.3 | 32.9 | 602.3 |
| " II | 0.1 | 3.1 | 6.0 | 132.0 | 23.5 | 411.3 | 32.6 | 574.4 |
| E-Iceland | | | 1977 | | 1978 | | Total | |
| 20-29 Jan. 1981 | | | N | W | N | W | N | W |
| Survey I | | | 4.3 | 117.5 | 15.2 | 312.5 | 19.5 | 430.0) |
| " II | | | 2.7 | 73.8 | 9.5 | 156.2 | 12.2 | 270.0) |
| " III | | | 3.2 | 87.3 | 11.4 | 234.7 | 14.6 | 322.0 |
| N-Iceland | | | 1978 | | 1979 | | Total | |
| 3 - 30 Nov. 1982 | | | N | W | N | W | N | W |
| Survey I | | | 0.3 | 7.5 | 18.1 | 334.7 | 18.4 | 342.2 |
| " II | | | 0.8 | 17.5 | 17.5 | 328.3 | 20.7 | 388.3 |

## MANAGEMENT

Initially regulatory measures were mainly precautionary in nature. In Iceland there was a closed season in spring and summer from 1973 to 1978 lasting for 2-4 months. In 1979 the closed season was extended lasting until 20 August and in 1980 until 5 September. In 1981 Icelandic vessels were, however allowed to fish capelin from 10 August but until 15 September the feeding grounds of the juvenile 1-2 group fish west of 21°W as well as south of 68°N remained closed to them.

In 1975 a minimum landing size of 12 cm was introduced with a minimum mesh size of 19.6 mm. In order to facilitate the release of the small juvenile capelin Iceland increased the minimum mesh size to 21 mm in 1981.

Since most of the capelin spawn only once and die thereafter the main management objective is to prevent the spawning stock from being fished to the level of reduced recruitment, not to mention recruitment failure.

In 1979, when fishing was stopped in the 3rd week of March, about 600,000 tonnes were left to spawn according to acoustic estimates of stock size, when account had been taken of the fishery and the natural mortality rate.

In 1980, it was decided that while gaining further experience it would be inadvisable to reduce the spawning stock to more than 2/3 of the 1979 level or 400,000 tonnes. This has been the management objective since then.

It was soon recognized that overfishing could well have taken place already by the time when the results from the October abundance survey became available. The reason for this is the large fishing power of the multinational fleet during periods of easy availability of the capelin. Already in 1979 a precautionary TAC was, therefore, advised to be revised according to results from stock abundance surveys in autumn and winter. This advice was not accepted.

Instead during the 3 year period 1979-81, preliminary and somewhat arbitrary TAC's were set prior to the fishing season after bilateral negotiations between Iceland and Norway. These preliminary TAC's were then divided and allocated to individual vessels. Recommended TAC's were based on results of the acoustic stock abundance surveys carried out in October/November and January/February each season. By that time, however, the Norwegian vessels had always fished their quota and so had a large part of the Icelandic boats. The result was that it proved impossible to have the fishery stopped in time and in particular the 1981 and 1982 spawning stocks were reduced to extremely low levels as shown in Figure 11.

A summary of this unfortunate procedure as well as the actual catches taken from the 1980, 1981 and 1982 spawning stocks is given in the text table below.

| 1979/80 | | | 1980/81 | | | 1981/82 | | |
|---|---|---|---|---|---|---|---|---|
| Prel. TAC | Rec. TAC | Catch | Prel. TAC | Rec. TAC | Catch | Prel. TAC | Rec. TAC | Catch |
| 650 | 850 | 962 | 775 | 450 | 680 | 700 | 381[1] | 626 |

1) The catch taken before 1 November. Zero TAC was then recommended pending further survey results.

Although it had proved difficult to assess the abundance of juvenile capelin it was evident from acoustic as well as 0-group surveys that the abundance of the 1980 year class, which was to spawn in 1983, was very low. The stock was considered to be in a grave condition even without any fishery taking place. A zero TAC was, therefore, recommended for the 1982-83 season pending results from the 1982 October abundance survey. This advice was accepted by all parties concerned, i.e. Iceland, Norway, the Faroes and EEC countries.

The results of the above survey corresponded to a spawning stock of about 190,000 tonnes in March-April 1983 and the fishing ban was extended to cover the whole season. As expected the 1983 January/February survey produced a slightly higher stock estimate or corresponding to about 220,000 tonnes of capelin spawning in March/April 1983. Estimates of spawning stock abundance as calculated from the January/February acoustic surveys for the period 1979-1983 are shown in the following text table.

| Year | 1979 | 1980 | 1981 | 1982 | 1983 |
|---|---|---|---|---|---|
| Tonnes | 600,000 | 300,000 | 160,000 | 140,000 | 220,000 |

The management objective of allowing 400,000 tonnes to spawn was, therefore, not reached except in 1979.

## Concluding remarks

The Icelandic stock of capelin does not carry a long history of exploitation. As has been related the fishery began in a modest way in the mid sixties and did not expand seriously until in the early seventies. Then came a period of 5 years when the catch from the spawning stock was near the half million mark annually. In this period the fishery mainly took place during the 3 months preceding the spawning process and apparently did not produce excessive mortality rates.

When the summer and autumn fishery came into being the catch increased to over one million tonnes from 1976-1978, remained near that level for 2-3 years whereupon the stock collapsed.

Unfortunately information on the abundance of the maturing or fishable stock did not become available until in the autumn of 1978. Since then the abundance of each years' spawning stock (1979-1983) has been assessed twice, i.e. in autumn and in January/February in the following year, by acoustic methods. There is little doubt in the minds of the researchers that obtained these abundance estimates that they are reliable and give a correct picture of the development of the stock during the 5 year period which they cover.

Nevertheless, these abundance estimates have been heavily questioned most of the time by fishermen and authorities alike and advice on TAC's based on them not fully accepted. Restrictions upon the fishery have been too lenient and been imposed too late. The stock has been overfished.

There are several reasons for this:

1. General reluctance to face the economic consequences of suddenly having to limit catches to a fraction of what they were.
2. The almost unbelievably rapid decrease in stock abundance to a level that was little more than the recommended spawning stock size.
3. Before the fishing season opened the preliminary TAC, generally set far too high, was divided between the vessels participating in the fishery. The The best part of the TAC had been taken before the October survey results became available while the Icelandic vessels, nevertheless, were in varying stages of filling their respective quotas. To have the fishery stopped in time was, therefore, difficult to say the least.
4. The occasional failure of some acoustic surveys, especially that from October 1981. Although the inadequacy of this survey was recognized at the time and a new survey executed immediately afterwards, its results were used to throw doubt on the applicability of the method by fishermen and authorities for a long time afterwards.
5. The nature of the capelin to aggregate and become available in areas of limited size the location of which may vary from year to year. The resulting concentration of the fishing effort gives the fishermen a false impression of abundance if their scouting effort is reduced from what it used to be. As the catch quotas and the extension of the closed season imposed in later years have indeed greatly lessened scouting activity, many of the fishermen have been under the impression that their own information on stock abundance is far better than it is in reality.
6. The improved acoustic gear, mounted in many vessels recently, also in most cases seems to have established an illusion of continued high abundance rather than helping in verifying the actual decline in stock size.

The faith in acoustics as a reliable tool of management is, however, improving. This is borne out by the fact that the authorities of all parties concerned accepted the advice of zero TAC for the 1982/83 season as described in a previous section.

In the absence of data on stock abundance prior to 1978 it is difficult to judge whether the recent decline in stock size is solely due to overfishing. Comparable data on the abundance of 0-group capelin are available from 1972 onwards (Figure 6). These 0-group indices point to a high level of recruitment until 1975/76 which is followed to a sharp downward trend and a much lower level since then.

The development coincides of course with the large increase in fishing effort brought about by the recent multinational summer and autumn fishery. It should, however, be pointed out that since 1976 large year classes of other fish species at the 0-group stage have, as a rule, not been observed in the Icelandic area. Therefore, the decline in the abundance and recruitment of the capelin stock, brought about by overfishing, has probably been accelerated by a prolonged period of inhospitable environmental conditions.

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